



Universidad de Valladolid



## Ph.D. Program in Business Economics

Ph.D. Dissertation:

### **Monetary policy and corporate investment: a panel-data analysis of transmission mechanisms in contexts of high economic policy uncertainty**

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in fulfillment of the requirements for the degree of  
Doctor of Philosophy (Ph.D.) in Business Economics

Universidad de Valladolid

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## Acknowledgements

This is probably the easiest and, at the same time, the most difficult part to write. It is easy because here, I don't need to rack my brain to come up with the most appropriate way to write out a research hypothesis or to paraphrase something I have said before. On the other hand, there are so many people to thank, and it is sometimes difficult to find the right words to do so.

To begin with, I would like to thank my Ph.D. advisors for their constant support and commitment over the last three years. Both Gabriel and Javier have shown that they possess three attributes that are essential to any self-respecting supervisor. First, they have extensive experience in finance and economics research and have been published in the top journals in the field. Second, they are very passionate about their work and devote many hours a day to their duties. Finally, and more importantly, they truly care about their Ph.D. students. I can safely say that I couldn't have carried out this arduous task without their help and support.

I'm also grateful to my colleagues Héctor and Víctor, who welcomed me with open arms when I started working on my master's thesis back in January 2018. From the very first moment, they made me feel at home and helped me gain a better understanding of the ins and outs of academia. In this sense, their advice has proven crucial in helping me to make the most of my Ph.D. years.

Nor can I fail to mention a few people who, to a greater or lesser degree, have contributed to my Ph.D. training over the last few years. First, I would like to thank Profs. Luis Vázquez and Luis Rodríguez for their support during the Master of Research I did at the University of

---

Salamanca between 2017 and 2018. Second, I'm also grateful to each and every person at the Departments of Financial Economics and Accounting, and Business Organization, Marketing, and Market Research for their kindness and willingness to help whenever I needed it.

I must also thank some professors from other departments and universities who were generous enough to allow me to audit their courses. I'm referring to Prof. Pilar Zarzosa (who teaches Econometrics at the UVa), Prof. Araceli Rodríguez (who teaches Macroeconomics I at the UVa), Prof. Carlos Borondo (who teaches Macroeconomics II and who helped with the first paper of my dissertation), Prof. Julio López (who teaches Macroeconomics III at the UVa using the flipped learning methodology), Prof. Benjamin Elsner (who teaches Econometrics at the UCD), and Prof. Oana Peia (who teaches Advanced Macro and supervised my research stay at the UCD). Finally, I would like to go back a few years and thank Prof. Anunciación Carrera from the Department of English Language at the UVa, who supervised my first foray into the realm of academic research and with whom I look forward to collaborating in the future.

I'm also indebted to the Ministry of Economic Affairs and Digital Transformation and the Regional Government of Castilla y León for their economic support under research projects ECO2017-84864-P and SA049G19. As a recipient of a Ph.D. Fellowship funded by the Regional Government of Castilla y León, the European Social Fund, and the University of Valladolid, I'm also grateful to these three institutions.

I would like to conclude by expressing my gratitude to the most important people in my life, namely my friends, family, and my partner. I'm grateful to all my friends, especially to two of them. I thank Mario for always being there and for those evenings of beers and chatting that helped me disconnect from work. I'm also grateful to Jaime, an economist I have always looked up to. I'm indebted to my dad, without whom I couldn't have completed my graduate education and who has always assisted me whenever I have needed him. I thank my mom and grandma for their love, their unconditional support in all the important decisions I have made, and for continuing to be a cornerstone of my life. Finally, I'm extremely grateful to Andrea, my other cornerstone, the person who has changed my life and who every day gives me the strength to continue pursuing my dreams, for her affection, love, and support, especially during the final stages of this dissertation.



## **Agradecimientos**

Quizás esta sea la parte más fácil y a la vez más difícil de escribir; fácil, porque aquí no tengo que reflexionar sobre cuál es la mejor manera de redactar una hipótesis o sobre cómo parafrasear algo que he escrito anteriormente; y difícil, porque hay mucho que agradecer y no siempre encuentra uno las palabras adecuadas para hacerlo.

Quiero empezar dando las gracias a mis directores de tesis por su apoyo y dedicación durante estos tres últimos años. Tanto Gabriel como Javier han demostrado que poseen tres cualidades imprescindibles para la dirección de una tesis doctoral. La primera es una dilatada experiencia en el campo de la investigación fruto de años publicando en revistas de alto impacto. La segunda es un verdadero interés y pasión por su trabajo, al que dedican más horas al día de las estrictamente necesarias. La última, y en mi opinión la más importante, es que realmente se preocupan por sus doctorandos. Creo que no me equivoco si digo que, sin ellos, esta tesis no habría sido posible.

También quiero incluir en la sección de agradecimientos a mis compañeros Héctor y Víctor, que me acogieron con los brazos abiertos cuando comencé a ir al despacho de forma regular allá por enero de 2018. Desde el principio, me hicieron sentir como en casa y me ayudaron a entender mejor los entresijos de la universidad y del mundo académico. En este sentido, su apoyo y consejos han sido cruciales para que haya sacado el máximo partido a estos tres años de formación predoctoral.

Tampoco quiero olvidarme de una serie de personas que, en mayor o menor medida, han jugado un papel importante en mi vida académica de los últimos años. En primer lugar, quiero

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dar las gracias a los profesores Luis Vázquez y Luis Rodríguez por su ayuda durante el máster de investigación que cursé en la Universidad de Salamanca entre 2017 y 2018. En segundo lugar, no puedo dejar de mencionar a todas y cada una de las personas que conforman los departamentos de Economía Financiera y Contabilidad y Organización de Empresas y Comercialización e Investigación de Mercados de la Universidad de Valladolid. Desde que llegué a la Facultad, siempre me han mostrado su simpatía y disposición para ayudar cuando lo he necesitado.

Me gustaría también dar las gracias a los profesores de otros departamentos y universidades que me han permitido asistir a sus clases como oyente. Me refiero a Pilar Zarzosa (profesora de Econometría de la UVa), a Araceli Rodríguez (profesora de Macro I de la UVa), a Carlos Borondo (profesor de Macro II de la UVa y que me ayudó con el primer artículo de mi tesis), a Julio López (profesor de Macro III de la UVa y cuyo modelo pedagógico de aula invertida espero poder aplicar en mis clases en un futuro no muy lejano), a Benjamin Elsner (profesor de Econometría de la UCD), y a Oana Peia (mi supervisora durante la estancia en la UCD y profesora de Macro Avanzada). Por último, voy a echar la vista atrás unos cuantos años para agradecer a Anunciación Carrera, profesora del departamento de Filología Inglesa de la Facultad de Filosofía y Letras de la UVa, con quien realicé mi primer trabajo de investigación y con quien me gustaría volver a colaborar en el futuro.

Estoy también en deuda con el Ministerio de Asuntos Económicos y Transformación Digital y con la Junta de Castilla y León por la financiación que ha otorgado a dos proyectos de investigación de los que he sido partícipe como miembro del equipo de trabajo: ECO2017-



84864-P y SA049G19. También agradezco a esta última institución, al Fondo Social Europeo y a la Universidad de Valladolid por la financiación predoctoral durante los últimos tres años.

Voy a ir concluyendo con la parte más importante de los agradecimientos, a saber: los dedicados a mis amigos, familia y pareja. Doy las gracias a todos mis amigos, y en especial a dos de ellos: a Mario, por estar siempre ahí y por esas tardes de cervezas y conversación que me ayudaban a desconectar de la tesis; y a Jaime, un referente para mí como economista y a quien siempre he admirado. También doy las gracias a mi padre, sin el cual no habría podido completar mi formación universitaria y que siempre me ha ayudado cuando lo he necesitado; y a mi madre y a mi abuela, por su amor, su apoyo incondicional en todas las decisiones importantes que he tomado y por seguir siendo un pilar fundamental en mi vida. Por último, estoy enormemente agradecido a Andrea, mi otro pilar, la persona que me ha cambiado la vida y quien me da fuerzas para seguir luchando cada día por cumplir mis sueños, por su cariño, amor y apoyo, especialmente en esta etapa final de la tesis.



**Abstract**

This Ph.D. dissertation explores the relationship between monetary policy, corporate investment, and economic policy uncertainty (EPU). Specifically, we address three interconnected research questions.

First, we examine the impact of conventional monetary policy on capital investment in contexts of high and low EPU. According to the real options approach, an increase in EPU is expected to have a positive effect on the value of the option to wait, encouraging firms to postpone their investment decisions and, as a result, depressing investment today. Building on this theory, we analyze whether and to what extent EPU undermines the investment-based transmission mechanisms of conventional monetary policy. Using a panel of U.S. public firms during the period 2000-2019, we estimate a panel-VAR model and find that expansionary monetary-policy shocks are less effective in stimulating capital investment when EPU is high. However, this effect is not uniform. We detect several asymmetries at the firm level. Particularly, in contexts of high EPU, firms with higher levels of investment irreversibility, operational inflexibility, and market power are less responsive to reductions in the policy rate.

Second, we study the effects of unconventional monetary policy on capital investment in the aftermath of the Great Recession. In order to stimulate the U.S. economy at the effective lower bound, the Federal Reserve employed two main policy tools: quantitative easing (QE) and forward guidance (FG). We investigate the impact of expansionary QE and FG announcements on capital investment by means of a sample of U.S. public firms and the

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panel-VAR methodology. We show that expansionary QE and FG announcements have a positive, but asymmetric impact on capital investment. Specifically, firms with higher investment irreversibility, operational inflexibility, and market power are less affected by unconventional monetary-policy shocks. Overall, our findings suggest that QE and FG are effective tools in fostering capital investment at the effective lower bound, although their impact is not uniform across firms.

Third, we draw upon the Black-Scholes-Merton option-pricing model to derive testable hypotheses on the effects of EPU and monetary policy on R&D investment. Using a panel of U.S. public firms and a fixed-effects model, we show that higher (lower) EPU and contractionary (expansionary) monetary policy exert a positive (negative) and significant influence on R&D investment. We also find that the interaction between EPU and the monetary-policy rate negatively affects R&D investment.

The findings of the present dissertation are relevant insofar that they shed light on several issues that may help fiscal and monetary authorities to gain a better understanding of the unintended consequences, as well as the potential collateral effects of their policies.

## Resumen

La presente tesis doctoral analiza la relación entre política monetaria, inversión empresarial e incertidumbre de política económica (IPE). En concreto, se abordan tres preguntas de investigación que relacionan estos tres elementos.

En primer lugar, analizamos el impacto de la política monetaria convencional sobre la inversión en bienes de capital en contextos de alta y baja IPE. De acuerdo con el enfoque de las opciones reales, un incremento en la IPE tiene un efecto positivo sobre el valor de la opción de esperar, incentivando a las empresas a posponer sus inversiones y, por tanto, reduciendo la inversión empresarial en el presente. Partiendo de esta teoría, analizamos en qué medida la IPE socava los mecanismos de transmisión de la política monetaria tradicional que afectan a la inversión en bienes de capital. Sirviéndonos de una muestra de empresas cotizadas estadounidenses para el periodo 2000-2019 y de la metodología VAR para datos de panel, concluimos que la política monetaria expansiva es menos efectiva cuando la IPE es alta. Sin embargo, los efectos de dichas políticas no son uniformes, sino que existen asimetrías a nivel de empresa. En concreto, en contextos de alta IPE, la inversión de aquellas empresas con mayor irreversibilidad de la inversión, inflexibilidad operativa y poder de mercado es menos sensible a reducciones del tipo de interés de política monetaria.

En segundo lugar, investigamos la influencia de la política monetaria no convencional sobre la inversión en bienes de capital en las postrimerías de la Gran Recesión. Con el objetivo de estimular la economía estadounidense después de alcanzar el llamado *límite inferior efectivo*, la Reserva Federal hizo uso dos herramientas de política no convencional:

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la expansión cuantitativa (QE, por sus siglas en inglés) y los preanuncios monetarios (PM). En este capítulo, examinamos el impacto de la QE y los PM sobre la inversión en bienes de equipo en una muestra de empresas cotizadas estadounidenses. Los resultados indican que ambas políticas tienen un efecto positivo, aunque asimétrico, sobre la inversión empresarial. En concreto, aquellas empresas con mayor irreversibilidad de la inversión, inflexibilidad operativa y poder de mercado son menos sensibles a las políticas monetarias no convencionales. En suma, nuestro análisis sugiere que tanto la QE como los PM son herramientas efectivas cuando se alcanza el *límite inferior efectivo*, aunque los efectos pueden ser desiguales a nivel de empresa.

Por último, recurrimos al modelo de valoración de opciones de Black, Scholes y Merton para desarrollar hipótesis testables sobre los efectos de la IPE y la política monetaria sobre la inversión en I+D. Partiendo de una muestra de empresas estadounidenses cotizadas y mediante un modelo de efectos fijos, concluimos que un incremento (reducción) en la IPE y una política monetaria contractiva (expansiva) ejercen una influencia positiva sobre la inversión en I+D. Además, nuestros resultados indican que la interacción entre la IPE y el tipo de interés de política monetaria tiene un efecto negativo sobre la inversión en innovación.

Los resultados de esta tesis son relevantes en la medida en que ayudan a las autoridades fiscales y monetarias a tener una mejor comprensión de las consecuencias indeseadas y efectos colaterales de sus políticas.

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## Introduction

Since the foundation of the Bank of England in the late seventeenth century, central banking and monetary policy have evolved considerably. Particularly, the last two decades have witnessed a dramatic change in the size and scope of central banks, moving from being monopolistic currency issuers and lenders of last resort to becoming active players in the shaping of financial markets and the economy as a whole. This shift was largely caused by the Great Recession, which forced central banks to resort to unconventional monetary-policy tools that had barely been used before to bring the economy back to growth. Yet conventional monetary policy has continued to be employed in times of prosperity, which suggests that traditional monetary policy based on fine-tuning the policy rate is still useful when the economy is far from the *effective lower bound*.

The transmission mechanisms of both conventional and unconventional monetary policy seem to weaken when uncertainty rises. In contexts of high uncertainty, monetary policy is less effective in stimulating the economy and, specifically, capital investment (e.g., Aastveit et al. 2017). In contrast, uncertainty may have a positive effect on a different form of corporate investment: R&D investment (e.g., Dixit and Pindyck 1995). In this Ph.D. dissertation, we examine the relationship between monetary policy, uncertainty, and corporate investments in both capital assets and innovation in the United States between 2000 and 2019. Concretely, we look at one type of uncertainty: economic policy uncertainty (hereinafter, EPU), which can be defined as uncertainty resulting from the economic effects of the actions or inactions of monetary authorities and governments (Baker et al. 2016).

We address three different, although interconnected, research questions. We start by investigating how capital investment is affected by conventional monetary policy in contexts of high and low EPU. In addition, we analyze the impact of unconventional monetary policy on capital investment in the aftermath of the Great Recession, a period of high EPU. Lastly, we examine the effects of EPU and monetary policy on R&D investment through the lens of the real options approach. Our results can be summarized as follows. First, capital investment is less responsive to both conventional and unconventional monetary-policy shocks in contexts of high EPU. This suggests that increasing EPU undermines the investment-based transmission mechanisms of monetary policy. Second, the effects of monetary policy are asymmetric at the firm level. Firms with higher levels of investment irreversibility, operational inflexibility, and market power are less affected by both conventional and unconventional monetary policy. And third, R&D investment behaves differently than capital investment in response EPU and monetary policy. Specifically, an increase in EPU and a contractionary monetary policy have a positive impact on R&D investment, encouraging firms to invest in innovation.

We rely on four strands of the literature to build our theoretical framework. First, we review the literature on capital investment under uncertainty, which dates to Keynes's *General Theory* (Keynes 1973). Second, we analyze the literature on the effects of monetary policy on the real economy, and more specifically, on capital investment. Third, we explore the recent studies on the effectiveness of unconventional monetary policy in the aftermath of the Great Recession. Finally, we look at the part of the real options literature that draws a parallel between R&D investments and call options.

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We contribute to these strands of the literature by shedding light on the asymmetric effects of both conventional and unconventional monetary policy on capital investment in the presence of high EPU. Particularly, we show that these asymmetries stem from three firm-level characteristics: investment irreversibility, operational inflexibility, and market power. Furthermore, we bring together two important bodies of research which has thus far remained separate: one that focuses on the effects of monetary policy on real variables; and another that explores the asymmetric impact of uncertainty on capital investment. Furthermore, we employ the real options approach to provide a sound rationale that explains the counter-intuitive effects of EPU and monetary policy on R&D projects. Previous research has focused on firm-level uncertainty. Instead, we investigate the influence of an exogenous source of uncertainty, namely EPU. Last but not least, this is, to the best of our knowledge, the first piece of research to consider the joint effect of EPU and monetary policy on R&D investment.

The rest of this dissertation is structured as follows. Chapter 1 reviews the relevant literature for our research. Chapter 2 examines the relationship between conventional monetary policy capital investment, whereas Chapter 3 addresses the effects of unconventional monetary policy in the aftermath of the Great Recession. Chapter 4 looks into how R&D investment is affected by both EPU and monetary from the real options perspective. Finally, Chapter 5 summarizes the results, discusses potential policy implications, and provides suggestions for future research.

## **Chapter 1. Literature review**

The present Ph.D. dissertation draws upon four strands of the literature. First, we review the literature that analyzes the relationship between capital investment and uncertainty. Second, we conduct a thorough revision of the transmission mechanisms of conventional (i.e., policy-rate-based) monetary policy, paying special attention to those affecting capital investment. Third, we examine the available evidence on the effects of unconventional monetary policy between 2008 and 2014. Finally, we explore the part of the real options literature that deals with R&D investment through the lens of the real options approach.

### **1.1. Capital investment under uncertainty**

The literature on the determinants and behavior of corporate investment dates to the 1960s with the neoclassical theory of investment as developed by Jorgenson (1967). Such theory states that a firm will invest until the marginal product of capital be equal to the user cost of capital. This implies that a firm's desired stock of capital will vary directly with the expected level of output and inversely with the user cost of capital.

Similar in essence to Jorgenson's neoclassical theory, Tobin's  $q$  theory of investment explains investment decisions using financial markets information (Tobin and Brainard 1968, 1976).<sup>1</sup> According to Tobin's  $q$  theory, a firm will invest as long as the ratio between the market value of capital assets and its replacement cost be higher than one. Therefore, firms

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<sup>1</sup> As shown by Hayashi (1982), Jorgenson's neoclassical theory of investment with adjustment costs and Tobin's and Brainard's  $Q$ -Theory of Investment are equivalent.

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will have the incentive to increase their capital stock when stock market prices rise, thereby taking advantage of new investment opportunities.

Since the 1980s, a large body of research has shown that Tobin's  $q$  mechanism may be undermined by the potential existence of financial constraints (e.g., Aivazian et al. 2005, Bond and Meghir 1994, Carpenter and Guariglia 2008, Fazzari et al. 1988, Gilchrist and Himmelberg 1995, 1999, Hubbard et al. 1995, Melander et al. 2017, Ng and Schaller 1996, Pindado et al. 2011, Stiglitz and Weiss 1981, Whited 1992). On the other hand, some authors find no relationship between financial constraints and corporate investment (e.g., Bond et al. 2004, Bond and Cummins 2001, Cleary 1999, Cummins et al. 2006, Erickson and Whited 2000, Kaplan and Zingales 1997, 2000)

However, the neoclassical theory of investment does not consider the impact of uncertainty on investment decisions.<sup>2,3</sup> As early as in 1936, Keynes pointed out that investment fluctuations over the business cycle result from uncertainty about the expected yield of capital assets (Keynes 1973). The irreversible nature of most capital investments is key to understanding the potential impact of uncertainty on investment. An investment in machinery and equipment is similar to exercising a call option insofar as it is irreversible: once the investment has been undertaken, the firm cannot fully recover the monetary value of the asset. Since uncertainty increases the value of the option to delay irreversible

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<sup>2</sup> Jorgenson was aware of this limitation. In a survey of the empirical literature on aggregate investment, Jorgenson (1971: p. 1142) admits that "the most important open question in the study of investment is the integration of uncertainty into the theory and econometrics of investment".

<sup>3</sup> This is not entirely true for Tobin's  $q$ , since expectations and, as a result, uncertainty play an essential role in explaining investment dynamics.

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investments, it is expected that a spike in uncertainty have a negative impact of the current level of investment (Abel and Eberly 1994, Bernanke 1983, Bertola and Caballero 1994, Caballero and Pindyck 1996, McDonald and Siegel 1986, Pindyck 1991).<sup>4</sup>

Despite some early papers that call into question the negative effects of uncertainty on capital investment (Abel 1983, Hartman 1972), the standard view on the relationship between uncertainty and investment can be found in Dixit and Pindyck (1994), who draw upon option-pricing theory to develop a systematic theory of investment under uncertainty.<sup>5</sup> According to the authors, under irreversible investment, uncertainty over future demand, input costs, exchange rates, tax and regulatory policies, as well as uncertainty over the future path of interest rates may have a depressing effect on capital investment, as they increase the value of waiting for new information (i.e., the value of the option to invest in the future).<sup>6</sup> These and other types of uncertainty that affect the value of the option to wait (e.g., Folta 1998, Vassolo et al. 2004) can be endogenous (which can be mitigated by the action of individual firms) or exogenous uncertainty (which cannot be controlled by firms) (Estrada et al. 2010, Folta and O'Brien 2004).

The empirical literature on the effects of uncertainty on capital investment can be classified into two groups, depending on whether authors use aggregate or disaggregate data.

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<sup>4</sup> Abel (1983) and Veracierto (2002) show that this negative effect depends upon several assumptions (e.g., market structure).

<sup>5</sup> Other seminal works on investment under uncertainty can be found in Schwartz and Trigeorgis (2001).

<sup>6</sup> Using a continuous-time model, Ingersoll and Ross (1992) find similar results regarding the impact of interest-rate uncertainty on investment.

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Table 1 shows the relationship between uncertainty and aggregate investment in a selection of pre-2000 papers (Carruth et al. 2000a).

**Table 1 – Early empirical studies on the relationship uncertainty-capital investment**

<b>Study</b>	<b>Country</b>	<b>Uncertainty proxy</b>	<b>Uncertainty effect</b>
Pindyck (1988)	US	Lagged stock market returns	Negative
Driver and Moreton (1991)	UK	Unconditional variance of output and inflation	Negative
Goldberg (1993)	US	Exchange rate volatility	None/Weak negative
Huizinga (1993)	US	ARCH estimates of conditional variances of inflation, real wages, and profits	Negative
Episcopos (1995)	US	ARCH estimates of conditional variances of interest stock market index, consumer spending, and GDP deflator	Negative
Price (1995, 1996)	UK	GARCH estimates of conditional variance of GDP	Negative
Ferderer (1993)	US	Risk premium computed from interest rate term structure	Negative
Ferderer and Zalewski (1994)	US	Risk premium computed from interest rate term structure	Negative
Carruth et al. (2000b)	UK	Gold price and abnormal return to holding gold	Negative

This table displays a selection of pre-2000 empirical studies on the relationship between uncertainty and capital investment.

The consensus seems to indicate that uncertainty has a negative impact on capital investment regardless of the proxy used to measure uncertainty. The literature since 2000 confirms these early findings.<sup>7</sup> Caggiano et al. (2014) finds that uncertainty shocks (as measured by shocks to the VIX index) have a negative effect on U.S. aggregate investment. Moore (2017) obtains similar results using Australian data. Finally, Baker et al. (2016) show that an increase in EPU, which is measured using a newspaper-based index developed by the authors themselves, negatively affects aggregate investment.

Nonetheless, most studies examining the effects of uncertainty on capital investment have relied upon disaggregate data at the firm level. This approach has three main advantages (Carruth et al. 2000a). First, it allows to identify potential asymmetries, which are not captured when using aggregate data. Second, potential problems of endogeneity (and more specifically, simultaneity) between uncertainty and capital investment can be properly addressed. Finally, by using firm-level data, heterogeneity resulting from the idiosyncrasy of each firm can be controlled for, which makes it easier to isolate the effects of uncertainty on investment.

In this respect, the pioneering study is that of Leahy and Whited (1996), who find a weak negative relationship between stock volatility and investment using a panel of U.S. firms.<sup>8</sup> Bontempi et al. (2009) and Guiso and Parigi (1999) show that market power and investment

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<sup>7</sup> The only exception is Sarkar (2000), who finds a positive relationship under certain circumstances.

<sup>8</sup> The importance of Leahy and Whited (1996) lies in the fact that the authors use firm-level data. However, it is not the first paper in using disaggregate data to test the relationship between uncertainty and capital investment. A few papers had used industry-level data before them (e.g., Campa 1993, Campa and Goldberg 1995, Ghosal and Loungani 1996, Goldberg 1993, Huizinga 1993).

irreversibility have a moderating effect on the relationship between uncertainty and investment. Bloom et al. (2007) find that the response of investment to demand shocks is lower when uncertainty is high due to investment irreversibility. Similarly, Bloom (2009) explains that uncertainty shocks affect investment via the real-options channel.

All these studies have something in common: they use a firm-level measure of uncertainty (e.g., firms' perceptions about future product demand, volatility of stock returns, volatility of profits growth, etc.).<sup>9</sup> Yet other papers focus on the effects of macroeconomic and policy-related uncertainty. Kang et al. (2014) find that EPU has a depressing effect on capital investment. Similarly, Gulen and Ion (2016) show that irreversibility moderates the relationship between EPU and capital investment. Particularly, firms with higher levels of investment irreversibility are more impacted by increases in uncertainty. Lastly, Jens (2017) analyzes the impact of gubernatorial elections as a source of exogenous uncertainty on capital investment and finds a negative effect.

## **1.2. The effects of conventional monetary policy on the economy**

Since the publication of Friedman and Schwartz (1971), the influence of conventional, policy-rate-based monetary policy on the real economy has been the focus of a multitude of theoretical and empirical studies. This influence works through several transmission channels, which can be divided into neoclassical (or traditional) and non-neoclassical (or credit-view-based) channels (Boivin et al. 2010, Mishkin 2016).

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<sup>9</sup> Bloom (2009) also uses an exogenous measure of uncertainty, namely the volatility of GDP forecasts.

Neoclassical channels are based on standard investment, consumption, and international trade models developed in the mid-twentieth century (Ando and Modigliani 1963, Fleming 1962, Friedman 2008, Jorgenson 1967, Modigliani and Brumberg 2013, Mundell 1963, Tobin 1969). There are two main transmission mechanisms affecting investment. First, the traditional cost of capital channel emphasizes the importance of the short-term policy rate in shaping the long end of the yield curve. Since firms usually rely upon long-term borrowings to fund new investments, a decrease in the policy rate tends to push down long-term yields, with the subsequent positive impact on capital investment (Taylor 1995). Second, Tobin's  $q$  mechanism works through the market value of firms (Tobin 1969). When the  $q$  ratio, which is calculated as the enterprise value of a firm divided by the replacement cost of capital, is high, firms will have the incentive to invest. Since the demand for stocks increases when monetary policy is eased, an expansionary shock will have a positive effect on investment.

The consumption-based channel suggests that monetary policy affects the net worth of individuals: lower interest rates lead investors to increase their demand for stocks and housing, which results in higher asset prices. This in turn increases the wealth of individuals, stimulating household consumption (Catté et al. 2004, Fair 2004). Finally, monetary policy influences international trade through the exchange-rate channel. Expansionary monetary policy tends to cause the domestic currency to depreciate, which in turn has a positive effect on exports and, as a result, on aggregate demand (Lee and Taylor 1994).

The non-neoclassical or credit-view-based channels are grounded upon the existence of imperfections in credit markets, such as information asymmetries. The literature on the impact of market imperfections in the relationship between monetary policy and real

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variables is vast (e.g., Bernanke and Blinder 1992, Bernanke and Gertler 1995, Iacoviello 2005, Iacoviello and Minetti 2008, Kashyap and Stein 1995, Peek and Rosengren 2012, Ramey 1993, Romer and Romer 1990). Within the credit view, three channels have been identified. The bank lending channel works through banks' reserves. Expansionary monetary policy increases banks reserves and, as a result, the supply of loans, with the subsequent positive impact on investment (Gertler and Gilchrist 1993). The balance sheet channel suggests that easing monetary policy increases the net worth of firms through higher asset prices. This in turn reduces adverse selection and moral hazard problems, resulting in firms borrowing more to make new capital investments (Carlstrom et al. 2010, Cúrdia and Woodford 2010). Lastly, the cash flow channel shows that expansionary monetary policy leads to lower interest payments, freeing up resources that firms may use to undertake new investments (Angelopoulou and Gibson 2009).

As shown, five of the channels discussed above have a direct or indirect impact on the corporate investment component of GDP: the traditional cost of capital channel, Tobin's  $q$ , the bank lending channel, the balance sheet, and the cash flow channel. To elucidate the existence of firm-level asymmetries in these transmission mechanisms, many studies have drawn upon disaggregate data. The seminal publication in this respect is that of Gertler and Gilchrist (1994), who find that contractionary monetary-policy shocks have a larger impact on small firms' sales and inventory. These results suggest that monetary policy may also affect corporate investment of small and large firms differently. Using a sample of Luxemburgish firms, Lünemann and Mathä (2003) find that younger firms are more responsive to shifts in the user cost of capital and, thus, to monetary policy. Gaiotti and

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Generale (2001) show that monetary policy has an asymmetric effect on corporate investment of Italian firms. Particularly, small firms, as well as less liquid firms and firms with lower cash flows are more affected by monetary policy. Cooley and Quadrini (2006) develop a general equilibrium model in which contractionary monetary-policy shocks have a greater (negative) impact on small firms' borrowing, which may lead them to reduce their investment more than large firms. Givens and Reed (2018) find that the effects of monetary policy on investment are unequal across different industries and sectors.

The literature mentioned so far rests upon the idea that expansionary monetary policy results in firms increasing their capital stock, which has a positive impact on aggregate investment and, consequently, on the overall economy. However, some recent literature suggests that monetary policy becomes less effective in contexts of high uncertainty. Aastveit et al. (2017) show that uncertainty moderates the relationship between monetary policy and aggregate investment. Particularly, when the VIX index is in its top decile, the effect of monetary policy on investment is halved compared to the situation when uncertainty is its bottom decile. More recently, Pellegrino (2021) finds that expansionary monetary-policy shocks are less effective in fostering capital investment when uncertainty is high.

### **1.3. Unconventional monetary policy in the United States**

The Great Recession marked a turning point in the way central banks conducted monetary policy. Before 2008, fine-tuning the short-term policy rate via purchases and sales of short-term Treasuries was the main mechanism whereby the Federal Reserve eased and tightened monetary policy. This changed when the effective lower bound was reached in late 2008,

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forcing the U.S. monetary authorities to draw upon two policy tools that had barely been used before: quantitative easing and forward guidance.<sup>10</sup>

### *1.3.1. Quantitative easing*

Quantitative easing (QE), the large-scale purchase of long-term securities (especially Treasuries and mortgage-backed securities or MBS), started in November 2008 and finished in October 2014. During this period, the Federal Reserve implemented three rounds of QE (QE1, QE2, and QE3) and a Maturity Extension Program (MEP), which increased the average duration of its portfolio from 1.6 years to 6.9 years and the size of its balance sheet by 400% (Bernanke 2020, Kuttner 2018). The aim of QE was to foster economic growth and to return to the pre-crisis unemployment levels through influencing long-term yields. This would be achieved through two main mechanisms (Kuttner 2018). First, since assets are not perfect substitutes, changes in the net supply of difference assets will affect their relative prices, giving rise to portfolio balance effects. For instance, the purchase of long-term Treasuries should also lower corporate bond yields by pushing investors into the corporate-bond market in search of higher yields (Blinder 2012). Second, QE sends a signal that monetary policy will continue to be expansionary for a significant period of time, which should have a depressing impact on long-term yields.

The empirical evidence suggests that QE was effective in lowering long-term yields, although not all QE announcements had the same impact. First, we consider the most typical

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<sup>10</sup> The main central banks in the world followed the example of the Federal Reserve and made use of several unconventional monetary-policy tools such as quantitative easing, forward guidance, or negative interest rates.

methodology to study the effects of QE on interest rates: event studies. Bauer and Neely (2014), Gagnon et al. (2011), and Krishnamurthy and Vissing-Jorgensen (2011) show that QE1 contributed to reducing 10-year Treasury and MBS yields by 88 and 123 basis points, respectively. D'Amico and King (2013) analyze the impact of QE1 on 10-year Treasury yields, concluding that QE1 helped reduce yields by 50 basis points via local-supply effects. Ehlers (2012) and Krishnamurthy and Vissing-Jorgensen (2011) find similar effects for QE2 and the MEP, but of a lower magnitude. The smaller effects of QE2 and subsequent QE announcements may be explained by the fact that financial markets would have anticipated and incorporated these effects into asset prices before formal announcements (Gagnon 2018). Finally, corporate yields were also affected by QE policies as suggested by Krishnamurthy and Vissing-Jorgensen (2011). Overall, Kuttner (2018) estimates that the cumulative impact of large-scale asset purchases on 10-year Treasury yields was at least -150 basis points.

By construction, event studies have one important limitation: they capture financial markets reactions over a short period of time. This means that we cannot be certain that the effects of QE announcements were long-lasting, a necessary condition for lower yields to have a significant impact on private spending decisions (Bernanke 2020). In fact, some studies have found that the impact of QE on long-term yields were short-lived (Greenlaw et al. 2018, Swanson 2021, Wright 2012). To overcome the inherent problems of event studies, time series econometric methods have been employed to assess the impact of QE announcements on bond yields, and more specifically on term premia. D'Amico et al. (2012) and Gagnon et al. (2011) use reduced-form models of the term premium, whereas Hamilton and Wu (2012) and Ihrig et al. (2018) resort to term structure models. Interestingly, taken

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together, all these four studies find that QE announcements lowered the 10-year term premium by 150 basis points, strikingly similar to the event-study results described above.

Lower long-term yields as a result of QE should have the same effect on the economy as expansionary monetary policy based on fine-tuning the policy rate: they should lower the cost of capital of firms, lead to wealth effects and stronger balance sheets, and boost exports via a weaker currency (Bernanke 2020). Overall, they should have a positive impact on the economy. Did large-scale asset purchases succeed in this respect in the aftermath of the Great Recession? Using a factor-augmented VAR, Wu and Xia (2016) analyze the impact of shocks to the shadow policy rate on the real economy. They show that QE reduced the unemployment rate by one percentage point between 2009 and 2013. Engen et al. (2015) finds similar results using a different methodology. Gertler and Karadi (2013) resort to a DGSE model to analyze the effects of QE on GDP and concludes that QE1 reduced the magnitude of the contraction of the U.S. economy by 3.5 percentage points. These positive macroeconomic effects work in part through investment-based mechanisms of monetary policy. Foley-Fisher et al. (2016) and Giambona et al. (2020) show that large-scale asset purchases managed to increase firm-level investment via the bond-lending channel.

### *1.3.2. Forward guidance*

Forward guidance (FG) is the other tool the Federal Reserve resorted to in the aftermath of the Great Recession. FG consists of communicating the future path of the policy rate. By promising to keep short-term interest rates low for a long period of time, monetary authorities exercise a downward pressure on long-term interest rates. As a result, forward guidance is

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expected to influence asset prices, as well as consumption, investment, and financing decisions

There are some examples of the use of forward guidance as a policy tool before the Great Recession. For instance, at a press conference in 1999, Masaru Hayami, the former Bank of Japan governor announced that “the Bank will maintain the zero interest rate policy until deflationary concerns are dispelled” (Shirai 2013). Similarly, during Alan Greenspan’s mandate, the FOMC promised to keep rates low “for a considerable period of time” (Bernanke 2020). Yet it was not until the Great Recession that FG became part of the policy framework of the Federal Reserve and other central banks.

There is ample evidence that forward guidance contributed to lowering medium and long-term yields after the Great Recession.<sup>11</sup> In an event-study framework and controlling for the impact of macroeconomic news, Moessner (2013, 2015a, b) finds that FG announcements reduced medium-term and long-term interest rates, as well as the term spread. Smith and Becker (2015) draw upon a VAR model to show that FG shocks had a significant impact on the slope of the expected federal funds rate curve. They also report that FG announcements have a similar effect on employment and prices during recessions to that of shifts in the policy rate in normal times. Moessner (2014) also finds a significant effect of FG on equity prices and uncertainty about future interest rates. Bernanke (2020) analyzes one-day responses to two specific FG announcements: August 9, 2011, and January 25, 2012. He shows that 2-year, 10-year, and 30-year Treasury yields decreased by between 10 and 27 basis points as a

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<sup>11</sup> For a survey on the theory and practice of forward guidance, see Moessner et al. (2017).

result of these announcements, while AAA corporate bond yields and MBS fell by 17 basis points.

Nonetheless, some studies find little effect of forward guidance on the economy. Hansen and McMahon (2016) employ a factor-augmented VAR to explore the influence of FG announcements on macroeconomic variables, concluding that the effects are small. Gavin et al. (2013) and Hagedorn et al. (2019) reach a similar conclusion, especially during recessions.

#### **1.4. R&D investment and the real options approach**

The term *real options* was coined by Myers (1977) with the idea of bringing financial options theory into the field of strategic management (Trigeorgis and Reuer 2017). A real option can be defined as the option, but not the obligation, to undertake a capital investment in the future. Trigeorgis (1996) identifies five types of real options: the option to defer an investment when a firm faces exogenous uncertainty (Campa 1994, Dixit and Pindyck 1994, McDonald and Siegel 1986, McGrath 1997); the option to expand or contract the manufacturing capacity (Damaraju et al. 2015, Hurry et al. 1992, Leiblein and Miller 2003, Pindyck 1988); the option to switch supplies, outputs, or inputs (Allen and Pantzalis 1996, Huchzermeier and Cohen 1996, Kogut and Kulatilaka 1994, Rangan 1998, Sakhartov and Folta 2014); the option to abandon a project (Adner and Levinthal 2004, Arend and Seale 2005, Dixit 1989, Elfenbein and Knott 2015, Lee et al. 2007); and the option to grow (Folta and Miller 2002, Kester 1984, Kogut 1991, Kogut and Kulatilaka 1994, Tong et al. 2008, Tong and Reuer 2006), which is the strand of literature relevant for our dissertation.

The starting point of this literature is the concept of growth option, which Kester (1984) defines as the opportunity to undertake a capital investment that is expected to generate a stream of cash flows in the future. Mitchell and Hamilton (1988) analyze R&D investments as strategic growth options. A firm that invests in an R&D project acquires a call option on real assets (i.e., a growth option). If the R&D investment succeeds in generating useful knowledge or innovation capabilities, firms will exercise this call option by undertaking a new capital investment that otherwise would not have been available. Dixit and Pindyck (1995) and Herath and Park (1999) point to the shortcomings of traditional valuation methods when applied to R&D investments, which should be considered means to generate investment opportunities that might or might not be taken advantage of in the future.

The issue of how to value R&D growth options and how these growth options affect the value of the firm has attracted substantial attention from the research community. Angelis (2000) develops a model that uses the costs and revenues resulting from implementing an R&D project to measure the option value of an R&D investment. Schwartz (2004) builds a real-options-based simulation approach to value R&D projects and patents, whereas Hsu and Schwartz (2008) develop a valuation model and apply it to the problem of R&D investment in the pharmaceutical industry. Grullon et al. (2012) show that an increase in R&D intensity is associated with an increase in the sensitivity of firm value to volatility. Kraft et al. (2018) analyze the impact of R&D growth options on firm value. They find that Tobin's  $q$  increases with idiosyncratic volatility (especially in R&D-intensive firms), suggesting that growth options have a positive effect on the market value of firms.

Like financial options, R&D growth options are expected to be influenced by uncertainty. An R&D project is expected to generate specific knowledge that will ultimately result in a new investment. An increase in uncertainty increases the probability of realizing large gains from that potential capital investment without increasing the expected losses since these are limited to the amount of the R&D investment. Based on this, Dixit and Pindyck (1995) argue that an increase in uncertainty over future market conditions could prompt R&D investments.

However, the empirical literature on the relationship between uncertainty and R&D investment is ambiguous. Some studies seem to support the idea that investments in innovation are positively affected by uncertainty. Stein and Stone (2013) report that uncertainty, measured by both implied and realized volatility, encourages R&D spending. Similarly, Vo and Le (2017) find that, when idiosyncratic return volatility increases, firms invest more in R&D. Cho and Lee (2020) find that an increase in uncertainty, which they approximate using the coefficient of variation of past sales, leads large firms to spend more in R&D.

A few papers find a negative relationship, mainly because of the option of deferral (i.e., the option to wait for new information) outweighing the option to grow. Goel and Ram (2001) show that uncertainty has a substantial negative impact on R&D investments due to the high irreversibility of this type of investments. Santiago and Vakili (2005) argue that, when the source of variability is market uncertainty, the effects on R&D investment are negative. In contrast, if uncertainty is related to market payoff, the impact of uncertainty is positive. Oriani and Sobrero (2008) find a U-shaped relationship between market uncertainty (i.e., the

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variability of expected future demand) and R&D investment: it reduces the value of R&D investment until a certain threshold is reached. After that, it incentivizes investments in innovation. They also show the existence of an inverted U-shaped effect of technological uncertainty (i.e., uncertainty related to the potential predominant role of a particular technology in an industry) on R&D investment. Using the coefficient of variation of past sales as a proxy for uncertainty, Czarnitzki and Toole (2011) report that high levels of uncertainty lead to fewer R&D investments, although patents mitigate these negative effects. Finally, Wang et al. (2017) analyze the influence of policy and market uncertainty on R&D investment and find a negative relationship.

### **1.5. Research gaps**

Based on the above review of these four strands of the literature, we identify three research gaps that will be tackled in the next three chapters. First, we examine the impact of conventional monetary on capital investment in contexts of high and low EPU and the firm-level asymmetries arising from it (Chapter 2). Second, we explore the asymmetric effects of two unconventional monetary-policy tools on capital investment in the aftermath of the Great Recession (Chapter 3). Finally, we look into how R&D investment is affected by EPU and monetary policy (Chapter 4).



## **Chapter 2. Conventional monetary policy and capital investment in contexts of high economic policy uncertainty**

Expansionary monetary policy based on fine-tuning the policy rate may affect capital investment through five transmission channels (Boivin et al. 2010). First, a decrease in the monetary-policy rate affects the cost of capital of firms, which in turn has a positive impact on corporate investments (Taylor 1995). Second, when monetary authorities decrease the policy rate to stimulate the economy, the demand for stocks increases. This leads to higher stock prices, encouraging investment via Tobin's  $q$  mechanism (Tobin 1969). Third, an easy monetary policy increases bank reserves and, as a result, the quantity of bank loans available, with the subsequent positive impact on investment (Gertler and Gilchrist 1993, Peek and Rosengren 1995). Fourth, the balance sheet channel suggests that expansionary monetary policy increases the net worth of firms via higher asset prices. This in turn reduces moral hazard and adverse selection problems, which results in firms borrowing more to fund new investments (Carlstrom et al. 2010, Cúrdia and Woodford 2010). Finally, lower interest rates as a result of an expansionary monetary policy causes interest payments to decrease, which frees up resources that firms may dedicate to new investments (Angelopoulou and Gibson 2009).

However, an increase in uncertainty may undermine these transmission mechanisms. The moderating effect of uncertainty in the relationship between monetary policy and investment can be explained drawing upon the real options approach, according to which uncertainty increases the value of the option to wait, encouraging firms to postpone

investments. This chapter aims to address to what extent EPU modulates the effect of conventional monetary policy on capital investment. We undertake a firm-level analysis to elucidate how expansionary monetary-policy shocks may affect firms with different idiosyncrasies in the presence of high EPU.<sup>12</sup> Specifically, we focus on three distinctive characteristics: investment irreversibility, operational inflexibility, and opportunity costs. Uncertainty increases a firm's option value to wait (and thus, the incentive to delay new investments) when: a) investment is irreversible (Gulen and Ion 2016); b) firms lack operational flexibility (Grullon et al. 2012); and c) the opportunity costs of not undertaking new investments in terms of loss of competitive advantages are low (Folta and Miller 2002).

Results show that EPU moderates the relationship between conventional monetary policy and capital investment. We find that, in the presence of high EPU, and in line with real options theory, firms with higher levels of investment irreversibility, operational inflexibility, and market power tend to be less responsive to monetary policy. This suggests that both the characteristics and composition of a country's business network play a moderating role in the relationship between capital investment and monetary policy when EPU is high.

We contribute to the literature in two ways. First, we shed light on the asymmetric effects of shifts in the monetary-policy rate on capital investment in the presence of high EPU. Second, we bring together two important bodies of research which has thus far remained

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<sup>12</sup> We follow Bernanke et al. (2005) and Boivin et al. (2010) and define monetary-policy shocks as shocks to the relevant monetary-policy rate that affect macroeconomic variables. In particular, we focus on expansionary shocks.

separate: one that focuses on the effects of monetary policy on real variables; and another that explores the asymmetric impact of EPU on capital investment. In particular, we investigate the moderating role of EPU in the relationship between conventional monetary policy and capital investment on a panel of U.S. firms over the period 2000-2019. In order to do so, the panel-VAR methodology introduced by Holtz-Eakin, Newey and Rosen (1988) is employed.

The rest of the chapter is structured as follows. Section 2.1 examines the theoretical relationship between conventional monetary policy and capital investment under uncertainty. Section 2.2 develops an empirical model to study the asymmetric impact of monetary policy on capital investment in contexts of high and low EPU and shows the results. Finally, Section 2.3 summarizes the key findings of this chapter.

### **2.1. Capital investment under uncertainty and monetary policy**

According to the real options approach, an investment opportunity is similar to a financial call option: firms have the right (but not the obligation) to increase their capital stock at any moment in the future. The purchase of a capital asset is akin to exercising a call option insofar as it is irreversible: once an investment has been undertaken, the firm cannot fully recover the monetary value of the asset (Pindyck 1991). The value of this option to invest is closely linked to uncertainty over the future cash flows the asset is expected to generate. Due to the irreversibility of most capital investments (Bertola 1988; Pindyck 1988), higher uncertainty over future economic conditions increases the value of waiting for new information, thereby providing an incentive for firms to delay their investment decisions. As a result, higher

uncertainty discourages immediate capital investment, and increases the value of the option to invest in the future.

When we incorporate the real options approach to the neoclassical theory of investment, we find that a firm will invest as long as the marginal product of capital be higher than its user cost of capital plus the value of the option to invest (Bloom et al. 2007). Let  $mpk = \frac{\alpha AK^{\alpha}L^{\beta}}{K}$  be the marginal product of capital under a Cobb-Douglas production function, and  $r_u = r + u$  the uncertainty-adjusted user cost of capital, where  $r$  is the user cost of capital as defined by the neoclassical theory of investment, and  $u$  the value of the option to invest in the future, which increases with uncertainty.<sup>13</sup> A new investment will be undertaken if and only if  $\frac{\alpha AK^{\alpha}L^{\beta}}{K} > r_u$  where  $r_u$  is higher than  $r$  when uncertainty spikes. An increase in uncertainty thus leads to an increase in firms' uncertainty-adjusted user cost of capital, raising the threshold that makes investment profitable. Therefore, for a given  $r$ , investment demand will be lower when uncertainty increases.

We can thus derive the following logical corollary with respect to the effectiveness of conventional monetary policy when EPU is high. In a traditional IS-LM framework, changes in the short-term policy rate tend to impact firms' investment decisions (Boivin et al. 2010). For instance, a decrease in the short-term policy rate reduces the user cost of capital,

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<sup>13</sup> For a Cobb-Douglas production function of the form  $Y = AK^{\alpha}L^{\beta}$ , the  $mpk$  is calculated as  $\frac{\partial y}{\partial K} = \alpha AK^{\alpha-1}L^{\beta} = \frac{\alpha AK^{\alpha}L^{\beta}}{K}$ . The user cost of capital would be defined as  $P_k + P_k (i + \delta)$ , where  $P_k$  is the price of a unit of capital,  $i$  is the real interest rate, and  $\delta$  the depreciation rate.

encouraging firms to undertake new investments.<sup>14</sup> Given that  $r_u = r + u$ , a decrease in  $r$  resulting from an expansionary monetary-policy shock in a context of high EPU will only reduce  $r_u$  if  $\frac{\partial r_u}{\partial r} > \frac{\partial r_u}{\partial u}$ . Since the value of  $u$  increases with EPU, central-bank policies aimed at stimulating investment through the user cost of capital would fail to achieve their purpose if the above condition were not to hold.<sup>15</sup> Accordingly, we state our first hypothesis:

**H1.** Expansionary monetary-policy shocks will be less effective in expanding capital investment in contexts of high EPU.

The impact of conventional monetary policy on capital investment may vary depending on a number of factors related to the idiosyncrasy of each firm. For instance, Gertler and Gilchrist (1994) show that the decline in investment of small firms after a monetary-policy shock is higher than that of large firms. Similarly, Givens and Reed (2018) find that the response of firms to anticipated monetary-policy shifts is asymmetric depending on the industry to which these belong. In the presence of high EPU, asymmetries in the impact of monetary policy on corporate investment may emerge based on other subtler characteristics, which in turn affect the value of the option to invest.

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<sup>14</sup> Since businesses tend to draw upon long-term financing to acquire new capital assets, the relevant interest rate for firms would not be the short-term policy rate, but longer-term interest rates (Boivin et al. 2010). However, if the expectations hypothesis of the term structure holds true, the short-term policy rate should affect investment through the influence of short-term rates on the long end of the yield curve, which in turn reduces corporate bond spreads.

<sup>15</sup> The incremental value of the option to invest in the presence of uncertainty may also weaken the bank-lending channel since the incentive to delay new investments and wait for new information may impact the demand for credit, undermining monetary authorities' efforts to increase the supply of credit via increases in bank reserves.

Given that the condition for undertaking a new investment ( $\frac{\alpha AK^\alpha L^\beta}{K} > r + u$ ) depends on the value of the option to postpone the commitment ( $u$ ), a decrease in the monetary-policy rate might not be expansionary enough to lower the threshold that makes investment profitable when  $u$  is high. As a result, a policy-rate cut is expected to have a lower impact on those firms with more valuable options to wait. The value of the option to wait depends on the trade-off between costs and benefits from immediate commitment (Estrada et al. 2010, Folta 1998, Folta and O'Brien 2004, Kogut 1991). The costs from immediate commitment increase in investment irreversibility (Bloom et al. 2007; Gulen and Ion 2016) and operational inflexibility (Grullon et al. 2012). Benefits from immediate commitment emerge in the form of competitive advantages from preemption, which represent the opportunity cost of waiting (Folta and Miller 2002, Smit and Ankum 1993, Trigeorgis 1991). Furthermore, the higher the uncertainty, the higher the costs and the lower the benefits from immediate commitment. This suggests that investment irreversibility, operational inflexibility, and opportunity costs may interact with EPU and thus make capital investment less sensitive to expansionary monetary-policy shocks.

First, we consider the irreversible nature of most capital investments. An investment is economically irreversible when a firm lacks the opportunity to recoup the capital invested without incurring high costs (Bernanke 1983). These recovering costs can arise from asset specificity, information imperfections, or market narrowness (Cooper 2006). Irreversibility entails comparing the value of immediate commitment to the value of investing in the future (McDonald and Siegel 1986). When EPU increases, capital-intensive firms are more likely to delay new projects, since irreversibility increases potential costs of unrecoverable

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immediate commitment above the present value of its uncertain benefits (Bloom et al. 2007; Gulen and Ion 2016). As a result, the value of the option to wait will be higher for these firms, making them less sensitive to expansionary monetary-policy shocks. Accordingly, we state the following hypothesis:

**H2.** In contexts of high EPU, expansionary monetary-policy shocks will be less effective in stimulating capital investments of firms with higher investment irreversibility.

Yet the potential costs from prompt investments do not only depend on irreversibility. Operational inflexibility also plays a significant role in a firm's ability to adapt to future adverse events. Operationally-inflexible firms tend to be more cautious when it comes to undertaking new investments (i.e., the value of the option to wait is higher), leading to a decline in investment demand in contexts of high EPU (Bontempi et al. 2009). Consequently, capital investments of those firms that have higher operational inflexibility will be less sensitive to expansionary monetary-policy shocks. This leads us to posit our third hypothesis:

**H3.** In contexts of high EPU, expansionary monetary-policy shocks will be less effective in stimulating capital investments of firms with higher operational inflexibility.

Postponing investments may involve opportunity costs in the form of diminished competitive advantages. Diminished competitive advantages may be the result of either preemption by rivals or the loss of the opportunity to preempt rivals (Folta and Miller 2002). If investment opportunities are not proprietary, the result of exercising them may be influenced by rivals' anticipation. In fact, such a threat may accelerate the early exercise of investment opportunities by firms trying to preserve their competitive advantages. And vice

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versa; when preemption risk is low, firms will be more prone to delaying new capital investments. Such competitive risks depend on a firm's relative competitive position. Under high EPU, firms with high market power tend to be less vulnerable to preemptive actions by rivals (Bontempi et al. 2009, Caballero 1991). Consequently, we conjecture that the following hypothesis should hold:

**H4.** In contexts of high EPU, expansionary monetary-policy shocks will be less effective in stimulating capital investments of firms with higher market power.

## **2.2. Empirical analysis**

### *2.2.1. Data and methodology*

In order to test the impact of monetary policy on capital investment and the moderating effect of EPU in this relationship, we use evidence from two different datasets, each of which contains annual data covering the period 2000-2019. First, we draw upon an unbalanced panel of U.S. publicly traded firms with a market cap of at least \$100 million from the Eikon database developed by Thomson Reuters. This database covers U.S. companies filing with the Securities and Exchange Commission. Following Pindado et al. (2011), we exclude from our sample financial firms and regulated utilities (Eikon industry groups 4300-4395 and 8200-8280). Second, we use a dataset of US macroeconomic variables from the Federal Reserve Bank of St. Louis.<sup>16</sup>

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<sup>16</sup> There are two exceptions: the shadow interest rate and the EPU index, which have been retrieved from the Federal Reserve Bank of Atlanta and [www.policyuncertainty.com](http://www.policyuncertainty.com), respectively.

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The methodology used is a reduced-form VAR that includes a cross-sectional dimension that is typical of panel data models. Panel VARs have many advantages (Canova and Ciccarelli 2013). First, they capture the dynamic interdependencies present in the model using very few restrictions. Second, panel VARs may be employed to estimate the effects of an exogenous shock in one variable on the dependent variable. Third, the unobservable heterogeneity arising when working with panel data can be controlled for using this methodology. Lastly, variables are assumed to be endogenous, which means that exogeneity assumptions are not, a priori, necessary to estimate the model. However, identifying restrictions may be imposed to determine the impact of exogenous shocks on the model (Abrigo and Love 2016).

Analytically, panel VAR models can be written as follows:

$$Y_{it} = AY_{it-p} + W_i + V_{it} \quad (1)$$

where  $Y_{it}$  is a vector of variables;  $A$  is an  $n \times n$  matrix including the coefficient of each lagged variable in each equation,  $W_i$  is an  $n \times 1$  vector incorporating the fixed effects of each equation, and  $V_{it}$  is the  $n \times 1$  vector of idiosyncratic errors satisfying  $E[V_{it}V_{it}'] = \Sigma$  and  $E[V_{it}V_{it-s}'] = 0, \forall s \neq 0$ .

All models are consistently estimated using a difference GMM estimator to address potential endogeneity issues. Such an estimator removes time-invariant fixed effects by first differencing the model and instruments the variables in differences ( $\Delta Y_{it}$ ) with the lagged values of the variables in levels ( $Y_{it-l}$ ) (Abrigo and Love 2016, Arellano and Bond 1991,

Holtz-Eakin et al. 1988, Roodman 2009).<sup>17</sup> Particularly, we use the same set of instruments for all estimated models: from  $t - 2$  to  $t - 4$ . Missing values of instruments are replaced with zeros to make estimated coefficients more efficient (Holtz-Eakin et al. 1988).

### 2.2.2. Model

The impact of monetary policy on capital investment is estimated using the following reduced-form panel-VAR model:

$$I_{i,t} = \sum_{j=1}^p \beta_j I_{i,t-j} + \sum_{j=1}^p \gamma_j Q_{i,t-j} + \sum_{j=1}^p \delta_j CF_{i,t-j} + \sum_{j=1}^p \theta_j MPR_{t-j} + \omega_i + v_{i,t} \quad (2)$$

where  $t$  denotes year,  $i$  denotes firm, and  $p$  the lag order;  $I$  is investment;  $Q$  represents Tobin's  $q$ ;  $CF$  is a cash-flow variable;  $MPR$  is the monetary-policy rate;  $\omega$  is a vector of firm-specific and industry-specific fixed effects;  $v$  is the serially-uncorrelated error term; and  $\beta$ ,  $\gamma$ ,  $\delta$  and  $\theta$  are matrices of coefficients capturing the marginal effects of the lagged variables on investment.

Investment ( $I$ ) is measured as capital expenditures in the year of the observation over beginning-of-year gross fixed assets (Carpenter and Guariglia 2008). The lagged dependent variable ( $I_{t-p}$ ) captures the dynamics of investment, as well as the accelerator effect (Aivazian et al. 2005). We use the ratio of enterprise value in the year of observation to gross fixed assets to proxy for Tobin's  $q$  ( $Q_{i,t-1}$ ) (Pindado et al. 2011). The potential existence of financial constraints is captured by cash flows ( $CF_{i,t-1}$ ) (Fazzari et al. 1988), calculated as

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<sup>17</sup> First-differencing the variables mitigates potential problems of unit roots (Abrigo and Love 2016).

after-tax profits plus depreciation normalized by gross fixed assets at the beginning of the year (Carpenter and Guariglia 2008).<sup>18</sup> The fed funds rate ( $MPR_{t-1}$ ) indicates the Federal Reserve's stance on monetary policy (Bernanke and Blinder 1992).<sup>19</sup> In order to identify periods of high and low EPU, we use the monthly EPU index ( $EPU$ ) developed by Baker, Bloom, and Davis (2016), which is based on newspaper coverage frequency of terms reflecting EPU. Since our model is based upon annual data, we construct a yearly variable by taking the average of monthly observations. Table 2 shows the summary statistics for the above variables.

**Table 2 – Summary statistics**

Variable	Mean	Median	St. dev.	Maximum	Minimum	Observations
$I_{i,t}$	.158	.0976	.2047	2.1278	.0014	29,867
$Q_{i,t}$	12.49	3.74	31.11	391.051	.2365	29,786
$CF_{i,t}$	-.749	0.1639	5.5435	4.96	-79.8	29,857
$EPU_t$	125.73	133.3	32.29	188.7	67.13	20
$MPR_t$	.0178	.0124	.0186	.0624	.0089	20

This table provides summary statistics for investment ( $I$ ), Tobin's Q ( $Q$ ), cash flows ( $CF$ ), the EPU index ( $EPU$ ), and the fed funds rate ( $MPR$ ). For the first three variables, observations below the 1<sup>st</sup> percentile and above the 99<sup>th</sup> percentile have been removed. The sample comprises 3,856 U.S. publicly traded firms with a market cap of at least \$100 million. Financials and utilities are excluded from the sample. The period covered goes from 2000 to 2019.

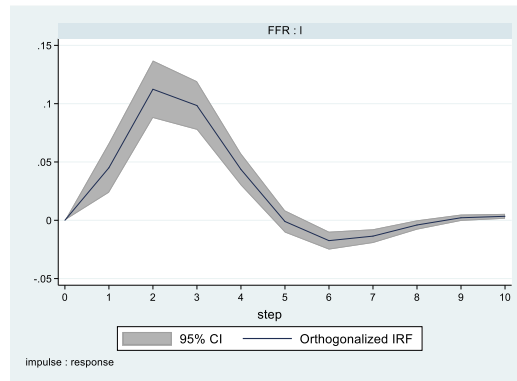
### 2.2.3. Results

To test the responsiveness of capital investment to expansionary monetary-policy shocks, we use the Cholesky decomposition and estimate orthogonalized impulse-response

<sup>18</sup> Observations below the 1st percentile and above the 99th percentile are removed for these three variables. The same variables enter all models in logarithmic and first-difference form.

<sup>19</sup> The fed funds rate enters all models in first-difference form.

functions. A short-run restriction is imposed so that investment reacts with a lag to monetary-policy shocks (Sims 1980). Figure 1 illustrates how capital investment reacts to a one-standard-deviation expansionary shock on the fed funds rate.<sup>20</sup> The shock results in corporate investment increasing to a maximum of 11.24% after two years. After that, investment starts to decline, reaching its pre-shock level in around five years.



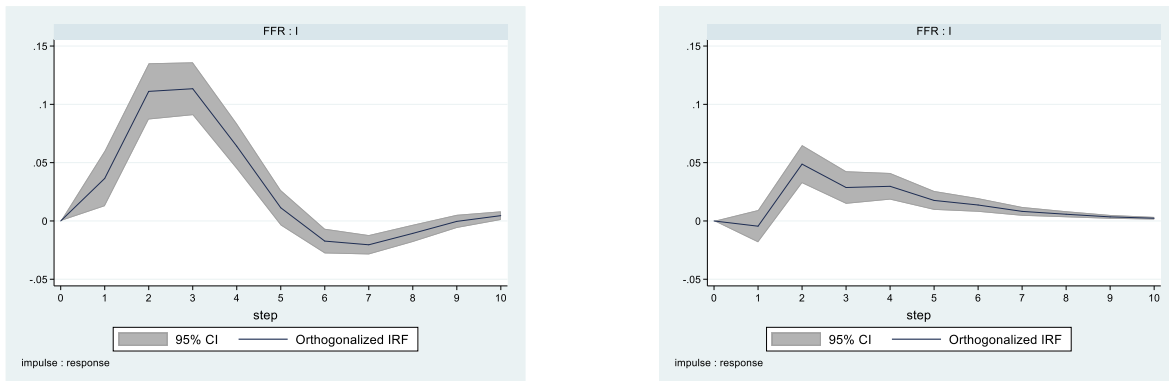
**Fig. 1.** Orthogonalized impulse-response function (*IRF*). Response of investment (*I*) to a one-standard-deviation expansionary shock on the fed funds rate (*FFR*) over ten periods. The shaded area represents a 95% confidence interval.

We now split our sample into two subsamples using the EPU index to gain a better understanding of the moderating role of uncertainty. In order to do so, we define a dummy variable that takes the value 1 when the EPU variable is in the top quartile, and we perform two separate estimations.<sup>21</sup> Figure 2 displays the impact of an expansionary policy-rate shock

<sup>20</sup> Table A in Appendix A contains the estimated first-order, panel VAR models corresponding to Figures 1 and 2. Lag-selection criteria can be found in the same appendix, Table B. All models meet the stability condition. Stability tests can be found in Appendix A, Figure A.

<sup>21</sup> The choice of this threshold is based on the dynamic panel threshold methodology developed by Seo et al. (2019) and Seo and Shin (2016). The threshold estimated by the model coincides almost exactly with the 75<sup>th</sup> percentile of the EPU index. Results can be found in Appendix A, Table C. Dynamic panel threshold models have previously been applied to firm-level data (Dang et al. 2012).

on investment in contexts of low EPU (left) and high EPU (right). In line with **H1**, monetary policy seems to be less effective when uncertainty is high. A one-standard-deviation shock increases investment to a maximum of 11.33% under low uncertainty as opposed to 4.87% in contexts of high uncertainty. This suggests that transmission mechanisms are undermined when EPU rises.<sup>22</sup>



**Fig. 2.** Response of investment to a one-standard-deviation expansionary shock on the fed funds rate in periods of low (left) and high (right) EPU.

#### 2.2.4. Robustness checks

In order to test the robustness of our results, we examine a number of alternative specifications.<sup>23</sup> We first use an alternative measure of monetary policy: the shadow rate (Wu and Xia 2016). This variable reflects the overall stance of monetary policy at the zero-lower bound (ZLB). When the fed funds rate is above 0.25%, the shadow policy rate broadly coincides with the fed funds rate. Below this threshold, the shadow policy rate can become negative. Figure 3 compares the fed funds rate with the shadow policy rate over the period

<sup>22</sup> Aastveit et al. (2017) obtain similar results using aggregate data.

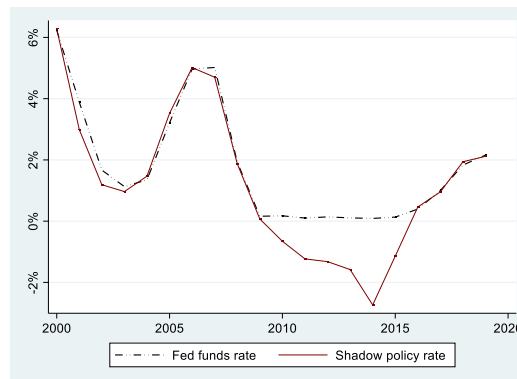
<sup>23</sup> Table 3 shows descriptive statistics for the variables used in the robustness checks.

2000-2019. In 2009, the shadow policy rate starts diverging from the fed funds rate, coinciding with the period where monetary authorities hit the ZLB. Orthogonalized impulse-response functions are displayed in Figure 4.<sup>24</sup> Results barely differ from those in our baseline model: investment is less sensitive to expansionary monetary-policy shocks in contexts of high EPU when using the shadow policy rate.

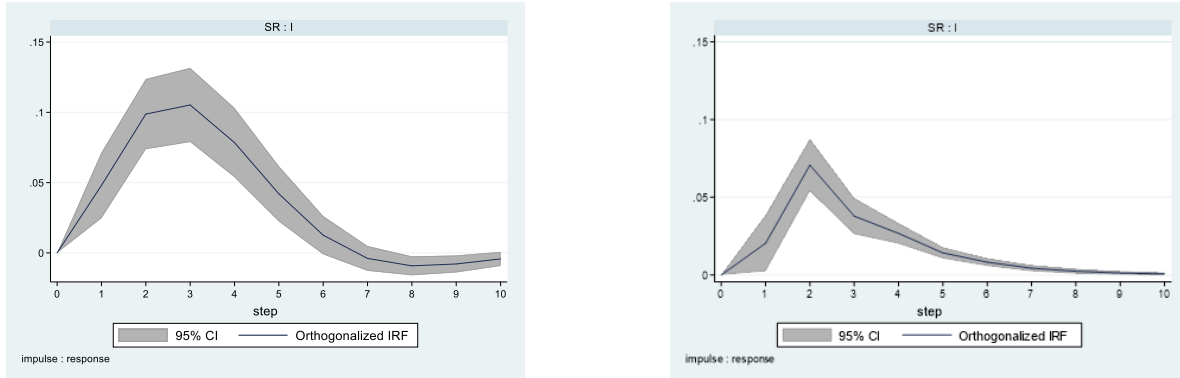
**Table 3– Summary statistics**

Variable	Mean	Median	St. dev.	Maximum	Minimum
$SR_t$	.0124	.0108	.0234	.0628	-.0274
$VIX_t$	.1949	.1764	.06	.3179	.1105
$CS_t$	.0262	.0275	.0062	.0404	.01689
$TS_t$	.00428	.0034	.0032	.0154	.0019

This table provides summary statistics for the shadow rate ( $SR$ ), the VIX index ( $VIX$ ), and the corporate ( $CS$ ) and TED ( $TS$ ) spreads. The period covered goes from 2000 to 2019. Data come from the Federal Reserve Bank of St. Louis except the shadow rate, which has been retrieved from the Federal Reserve Bank of Atlanta.

**Fig. 3.** Fed funds rate vs. Shadow policy rate (2000-2019).

<sup>24</sup> Table D in Appendix A contains the estimated first-order, panel VAR models corresponding to Figures 4 to 6. Lag-selection criteria can be found in the same appendix, Table E. All models meet the stability condition. Stability tests can be found in Appendix A, Figure B.

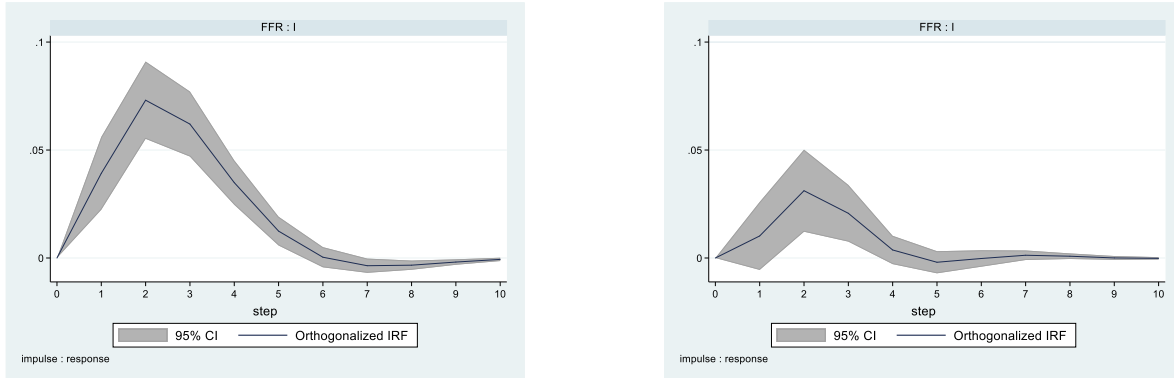


**Fig. 4.** Response of investment to a one-standard deviation expansionary shock on the shadow rate in periods of low (left) and high EPU (right).

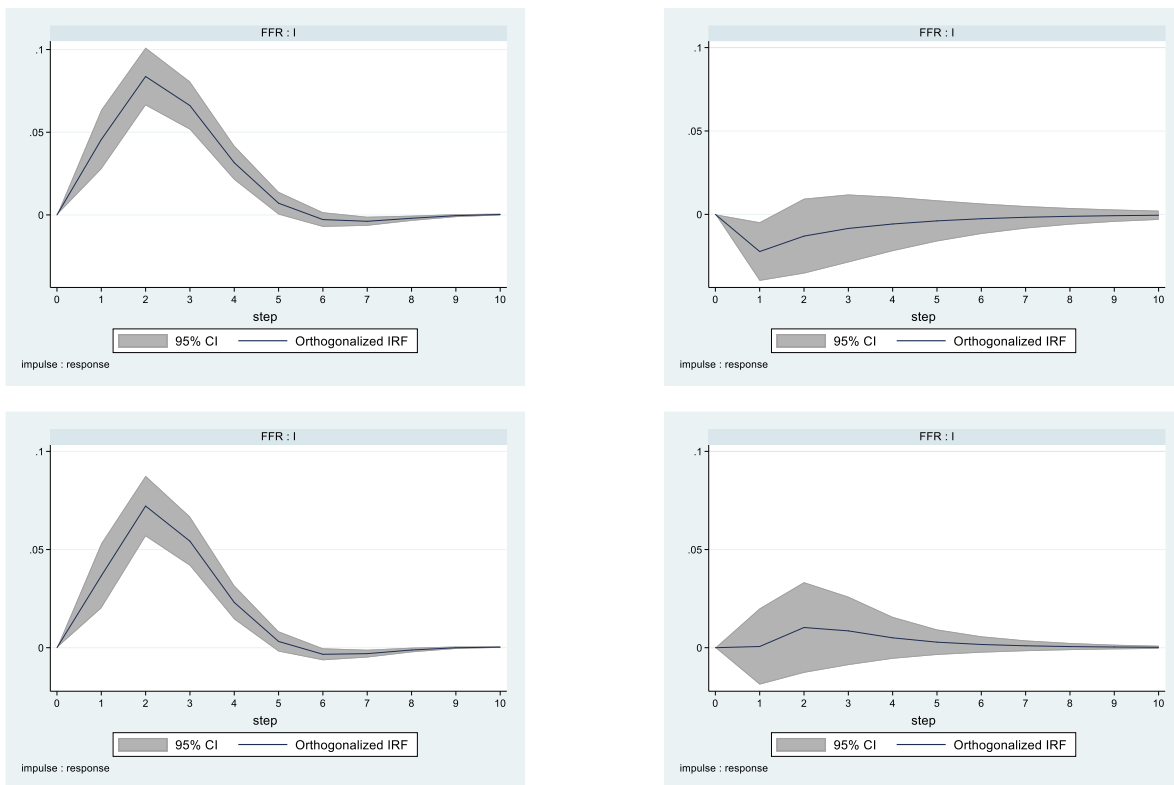
We also use alternative measures of uncertainty by replacing the EPU index in the initial model. First, we follow Bekaert et al. (2013) and Caggiano et al. (2017) use the VIX index.<sup>25</sup> Second, we use bond spreads as uncertainty proxies (Bachmann et al. 2013, Caldara et al. 2016, Gilchrist and Zakrajšek 2012, Stock and Watson 2012). In particular, two different bond spreads are employed: the corporate spread and the TED spread.<sup>26</sup> Based on these three uncertainty proxies, the sample is again divided into two subsamples using a dummy that takes the value 1 when the variable is in the top quartile (periods of high uncertainty) and 0 (periods of low uncertainty) otherwise. Impulse-response functions in Figure 5 (where uncertainty is measured through the VIX index) and Figure 6 (uncertainty is proxied using two spreads) are consistent with our initial estimates: an expansionary monetary-policy shock is less effective when uncertainty is high.

<sup>25</sup> We build a yearly variable by averaging monthly data.

<sup>26</sup> The corporate spread variable is built using the spread of Moody's Baa corporate bond yield over the 10-Year Treasury bond yield. The TED spread is calculated as the difference between the 3-Month LIBOR based on US dollars and the 3-Month Treasury Bill. Both variables are built by taking the yearly average of monthly data.



**Fig. 5.** Response of investment to a one-standard-deviation expansionary shock on the fed funds rate in periods of low (left) and high (right) uncertainty. The VIX index is used to measure uncertainty.



**Fig. 6.** Response of investment to a one-standard deviation expansionary shock on the fed funds rate in periods of low (left) and high (right) uncertainty. A corporate spread (first row) and the TED spread (second row) are used to measure uncertainty.



### 2.2.5. Firm heterogeneity in the influence of monetary policy on capital investment

To disentangle the asymmetric effects of expansionary monetary policy on investment in contexts of high EPU, we divide the sample using proxies for investment irreversibility, operational inflexibility, and market power and estimate orthogonalized impulse-response functions.<sup>27</sup>

Following Gulen and Ion (2016), we use the capital intensity ratio of firms, measured as property, plant and equipment over total assets (*PPE*) to measure investment irreversibility. The rationale behind this choice is closely linked to two typical characteristics of capital-intensive firms: the high cost of new capital investments and the difficulties involved in disposing of or reusing the machinery in a different line of business should the investment project not go as planned. Operational inflexibility is measured using fixed costs over sales (*OF*).<sup>28</sup> A firm that cannot adjust its workforce when needed without incurring significant costs can be said to lack operational flexibility (Grullon et al. 2012). Finally, we use the price-cost margin of firms (*PCM*) to quantify market power as it tends to be higher for firms with more monopoly power (Bontempi et al. 2009, Domowitz et al. 1986).<sup>29,30</sup> Table 4 displays summary statistics for these three variables.

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<sup>27</sup> The dummies used to split the samples take the value 1 when the variable is above the sample median, and 0 otherwise. In the case of market power, the dummy takes the value 1 when the variable is above the industry median.

<sup>28</sup> Fixed costs are proxied using the accounting entry “Selling, Administrative and General Expenses.”

<sup>29</sup> The price-cost margin is calculated as  $\frac{Sales + \Delta Inventory - Cost\ of\ goods\ sold}{Sales}$ .

<sup>30</sup> Observations below the 5th percentile and above the 95th percentile are removed for these three variables.

**Table 4 – Summary statistics**

Variable	Mean	Median	St. dev.	Maximum	Minimum	Observations
<i>PPE</i>	.231	.1659	.1997	.7998	.01038	31,875
<i>OF</i>	.3404	.239	.3443	2.67	.0393	30,239
<i>PCM</i>	.4899	.4398	.2449	1	.1094	29,236

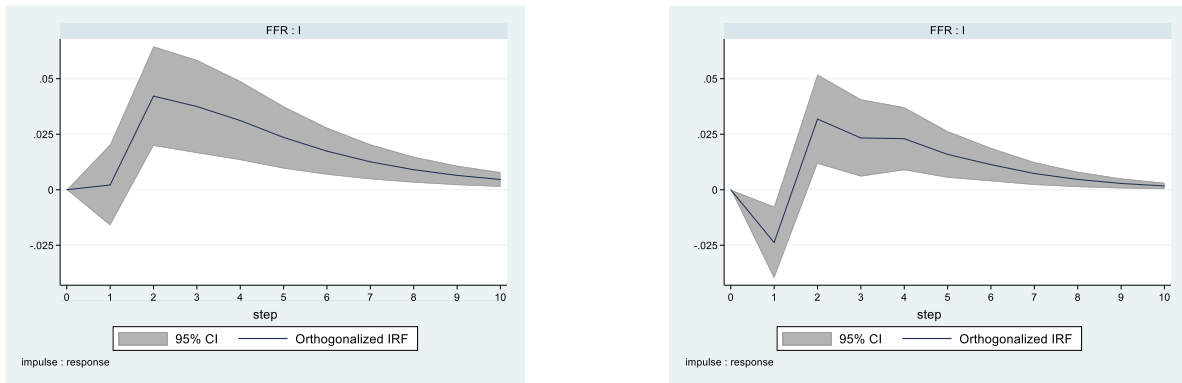
This table provides summary statistics for property, plant, and equipment (*PPE*), fixed costs (*OF*), and the price-cost margin (*PCM*). Observations below the 5<sup>th</sup> percentile and above the 95<sup>th</sup> percentile have been removed. The sample comprises 3,856 U.S. publicly traded firms with a market cap of at least \$100 million. Financials and utilities are excluded from the sample. The period covered goes from 2000 to 2019. Data come from Eikon Reuters.

Figures 7 to 9 display the impact of a one-standard-deviation expansionary monetary-policy shock on capital investment.<sup>31</sup> In all figures, left (right) panels show the effect on the subsample where the value of the option to wait is assumed to be lower (higher) and, therefore, the impact of monetary policy should be higher (lower). Figure 7 shows the impact of an expansionary monetary-policy shock on investments for firms with low (left) and high (right) investment irreversibility. Monetary policy seems to be less effective when irreversibility is high. This result appears to provide support for **H2**: the irreversibility effect increases the value of the option to invest, pushing capital intensive firms to postpone their investments in contexts of high EPU.

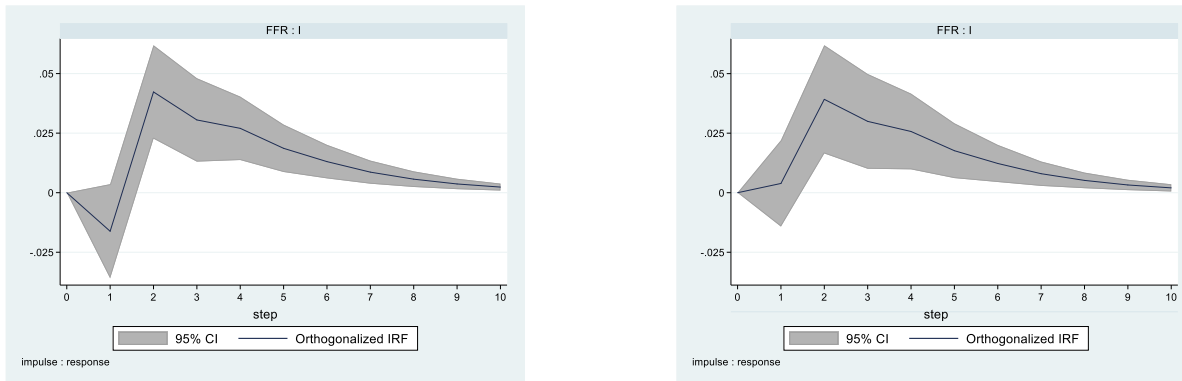
In Figure 8, the effects of an expansionary monetary-policy shock on investment are shown for firms with low (left) and high (right) operational inflexibility. Operational inflexibility is expected to make firms less responsive to monetary-policy shocks as the value of the option to invest increases under uncertainty, encouraging businesses to postpone their

<sup>31</sup> Table F in Appendix A contains the estimated first-order, panel VAR models corresponding to Figures 7 to 9. Lag-selection criteria can be found in the same appendix, Table G. All models meet the stability condition. Stability tests can be found in Appendix A, Figure C.

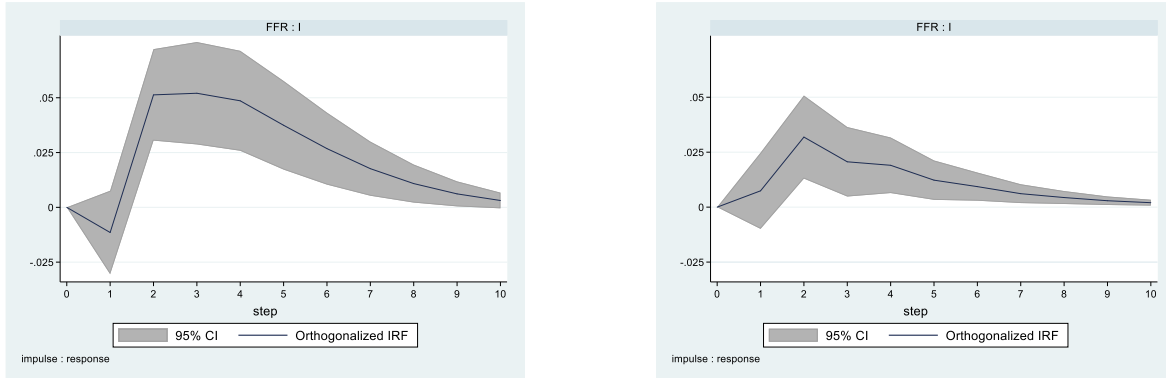
investment decisions. Yet results in Figure 8 suggest that the difference is barely noticeable, providing limited support for **H3**. Finally, Figure 9 displays the impact of an expansionary monetary-policy shock on investment for firms with low (right) and high (left) market power. In line with **H4**, the transmission mechanisms of monetary policy are undermined for firms with substantial market power when EPU is high.



**Fig. 7.** Response of investment to a one-standard deviation expansionary shock on the fed funds rate in periods of high uncertainty for firms with low (left) and high (right) investment irreversibility.



**Fig. 8.** Response of investment to a one-standard deviation expansionary shock on the fed funds rate in periods of high uncertainty for firms with low (left) and high (right) operational inflexibility.



**Fig. 9.** Response of investment to a one-standard deviation expansionary shock on the fed funds rate in periods of high uncertainty for firms with low (left) and high (right) market power.

### 2.3. In a nutshell

In this chapter, we explore the effects of conventional monetary policy on capital investment in the presence of high EPU. By means of a panel of US firms over the period 2000-2019, we find that the transmission mechanisms of monetary policy affecting investment are weakened when EPU increases. Results are robust to using different measures of uncertainty and monetary-policy rates. At the firm level, and consistent with the real options approach, our results suggest that firms with higher levels of investment irreversibility, operational inflexibility, and market power tend to be less responsive to expansionary monetary-policy shocks.

## **Chapter 3. Unconventional monetary policy and capital investment in the aftermath of the Great Recession**

The Federal Reserve has traditionally used the federal funds rate to achieve its dual mandate of maximum employment and stable prices. By increasing or decreasing the federal funds rate target the Federal Reserve influences aggregate demand, boosting (cooling down) the economy when deflationary (inflationary) pressures emerge. However, when the effective lower bound (ELB) was reached in late 2008, conventional monetary policy based on policy-rate management became ineffective, thereby undermining traditional transmission mechanisms of monetary policy.<sup>32</sup> In addition, the bankruptcy of Lehman Brothers further weakened the federal funds rate channel by causing a significant disruption in the overnight interbank market, with the subsequent negative impact on the bank lending channel (Afonso et al. 2011).

In this situation, the Federal Reserve was forced to draw upon two unconventional monetary-policy tools in order to boost the economy and meet its policy objectives: large-scale asset purchases (also known as quantitative easing or QE) and forward guidance (FG). Prior research has analyzed the impact of QE and FG on the economy, as well as the potential costs and risks associated with the use of these unconventional monetary-policy tools.<sup>33</sup>

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<sup>32</sup> As pointed out in Bernanke (2020), the term *effective lower bound* includes the possibility of negative short-term policy rates. However, in the US, the effective lower bound coincided with the *zero lower bound*.

<sup>33</sup> For a comprehensive review of the effects and risks of unconventional monetary policy, see Kuttner (2018) and Bernanke (2020).

However, evidence on the specific effects which such tools have on capital investment and the asymmetries that may arise at the micro level remains relatively scarce.

In this chapter, we address this gap by examining the firm-level effects of unconventional monetary policy in the aftermath of the Great Recession. In particular, we focus on three firm-level characteristics that may undermine the transmission of unconventional monetary-policy tools, especially in contexts of high EPU: investment irreversibility, operational inflexibility, and opportunity costs resulting from the potential loss of competitive advantages. First, we explore the aggregate impact of unconventional monetary policy on capital investment using a sample of U.S. public firms between 2000 and 2018. We find that both expansionary QE and FG announcements have a positive effect on capital investment. Second, we split the sample based on investment irreversibility, operational inflexibility, and opportunity costs in order to identify firm-level asymmetries. Our results suggest that the impact of unconventional monetary policy on capital investment is asymmetric at the firm level. Specifically, investment of those firms that have higher levels of investment irreversibility, operational inflexibility, and market power is less affected by expansionary QE and FG announcements.

The rest of this chapter is structured as follows. In section 3.1, we examine the investment-based transmission mechanisms of unconventional monetary policy and the potential asymmetries arising at the firm level. In section 3.2, we undertake an empirical analysis of the impact of expansionary QE and FG announcements on capital investment. Section 3.3 concludes this chapter by summarizing the main results.

### **3.1. The effects of unconventional monetary policy on capital investment**

In December 2008, the federal funds rate target reached the ELB, and the Federal Reserve was forced to resort to two main unconventional monetary-policy tools in order to stimulate the economy and meet its dual mandate: quantitative easing and forward guidance.

QE refers to the large-scale purchase of a wide variety of long-term assets. The Federal Reserve carried out three long-term asset purchase programs and a maturity extension program over the period November 2008-October 2014. In total, the Federal Reserve purchased around \$3.8 trillion in assets, enlarging its balance sheet by a factor of five (Bernanke 2020, Kuttner 2018). There are at least three transmission channels through which QE may affect capital investment. First, the purchase of private-sector bonds exerts downward pressure on corporate yields, reducing their risk premium over riskless government Treasuries of similar maturity and lowering borrowing costs for firms (Blinder 2010).<sup>34</sup> Lower borrowing costs encourage firms to issue bonds, which are used to fund new investments (Chen et al. 2016, Grimm et al. 2020, Grosse-Rueschkamp et al. 2019).<sup>35,36</sup> Second, buying medium-term and long-term Treasury securities lowers corporate yields in

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<sup>34</sup> It should be noted that the Federal Reserve limited its purchases to Treasury securities and mortgage-backed securities, refraining from purchasing corporate bonds in either primary or secondary markets. However, other central banks purchased corporate debt as part of their QE programs (Bernanke 2020, Kojien et al. 2017).

<sup>35</sup> A decrease in corporate bond yields resulting from QE policies does not always result in firms undertaking new investments. For instance, Todorov (2020) finds that firms that benefited from the ECB's Corporate Sector Purchase Program (CSPP) employed the new funds to increase dividend payments.

<sup>36</sup> The mechanism explained in Grosse-Rueschkamp et al. (2019) is closely linked to corporate bond yields, but works in a different way. If firms move from bank loans to corporate bonds because of QE programs, banks will face lower regulatory and economic constraints, enabling them to increase lending to firms that did not benefit from corporate bond purchases. This in turn has a positive impact on investment of these firms.

those maturities via the bond-lending channel, i.e., by pushing investors into corporate bonds and other private-sector securities through portfolio balance effects (Blinder 2012, Gagnon et al. 2011, Giambona et al. 2020, Gilchrist and Zakrajšek 2013, Swanson 2021). Lower corporate bond yields prompt firms to invest more (Foley-Fisher et al. 2016, Giambona et al. 2020). Third, lower Treasury and corporate bond yields may result in higher equity prices via portfolio balance effects (Bernanke 2020). In search of higher yields, investors are pushed into riskier assets, mainly equities. This in turn increases firms' Tobin's  $q$ , with the subsequent positive impact on equity issuances and capital investment. Finally, QE improves financial conditions in the economy as a whole, exerting a calming effect on markets and favoring the issuance of corporate bonds to finance new investments (Lo Duca et al. 2016). This evidence regarding the effects of QE leads us to posit our fifth hypothesis:

**H5.** Expansionary QE announcements exert a positive influence on capital investment.

Forward guidance involves communicating information about the future path of the policy rate. According to Campbell et al. (2012), this communication can be *Delphic* (public forecasts of macroeconomic indicators) or *Odyssean* (a commitment to maintain the policy rate at a certain level for a specific period of time or until some policy targets are met).<sup>37</sup> Forward guidance may affect capital investment in three main ways. First, expansionary FG announcements have a depressing effect on both components of long-term yield curve rates: the term premium and the expected path of short-term interest rates (Smith and Becker 2015).

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<sup>37</sup> Moessner et al. (2017) introduce a third form of forward guidance communication, which they refer to as *Aesopian*. Like *Delphic* forward guidance, *Aesopian* involves communicating forecasts, but under special circumstances (e.g., the ELB).



This in turn results in lower corporate bond yields via portfolio balance effects (Bernanke 2020, Campbell et al. 2012, Hansen and McMahon 2016), incentivizing leveraged investments at the firm level. Second, expansionary FG announcements lead to higher equity prices (Hansen and McMahon 2016, Moessner 2015c), encouraging firms to invest through Tobin's  $q$  transmission channel. Finally, expansionary FG announcements tend to reduce uncertainty by anchoring expectations about the future path of interest rates (Ehrmann et al. 2019). Lower uncertainty strengthens the investment-based transmission mechanisms of monetary policy by reducing the value of the option to wait vis-à-vis the value of immediate commitment (Gulen and Ion 2016, de la Horra et al. 2021)<sup>38</sup>. Based on this, we state the following hypothesis:

**H6.** Expansionary FG announcements exert a positive influence on capital investment.

The impact of unconventional monetary policy on capital investment is not expected to be uniform. Asymmetries may arise at the micro level depending on the idiosyncrasy of firms. Prior literature suggests that monetary-policy shocks do not affect firms and industries equally. For instance, Gertler and Gilchrist (1994) show that investment of large firms investment is less sensitive to shifts in monetary policy than that of small firms. Similarly, Givens and Reed (2018) find that the effects of monetary policy on investment are unequal across different industries and sectors. In contexts of high EPU, these asymmetries may be linked to certain characteristics that make some firms less responsive to unconventional monetary policy, undermining the efforts of monetary authorities to stimulate investment.

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<sup>38</sup> De la Horra et al. (2021) contains the findings of Chapter 2, which have been published in the *International Review of Economics & Finance*.

We identify at least three characteristics that are linked to the value of a firm's option to postpone its investments: investment irreversibility, operational inflexibility, and opportunity costs.

When EPU increases, capital-intensive firms are more likely to delay new investments because the value of the option to wait increases in investment irreversibility (Bloom et al. 2007, Gulen and Ion 2016). This would make unconventional monetary-policy measures less effective in stimulating capital investment. Similarly, operational inflexibility, understood as “firms’ [in]ability to adjust their workforce in response to changes in economic conditions” (Grullon et al. 2012: p. 1511), has a negative effect on investment in the presence of high EPU. In effect, inflexible firms tend to be more cautious before committing to new investments due to the high costs of adjusting their workforce, undermining monetary-policy efforts to stimulate investment demand. Accordingly, we state the following hypotheses:

**H7.** Firms with higher levels of investment irreversibility are less responsive to unconventional monetary-policy shocks.

**H8.** Firms with higher levels of operational inflexibility are less responsive to unconventional monetary-policy shocks.

Finally, firms with lower opportunity costs may be less affected by unconventional monetary policy since the cost of postponing new investments in times of rising EPU is lower for these firms. These opportunity costs may emerge in the form of diminished competitive advantages (Folta and Miller 2002, Smit and Ankum 1993, Trigeorgis 1991). Firms with robust competitive advantages will have fewer incentives to exercise their option to invest

immediately since the opportunity costs of not doing so will be lower, reducing the potential impact of monetary policy on investment for these firms. Competitive advantages in turn depend on a firm's relative competitive position. Firms with high market power face lower opportunity costs since their competitive position is less vulnerable to preemptive actions by rivals (Bertola and Caballero 1994, Bontempi et al. 2009). Consequently, our ninth hypothesis is stated as follows:

**H9.** Firms with higher levels of market power are less responsive to unconventional monetary-policy shocks.

### **3.2. Empirical analysis**

#### *3.2.1. Model and data*

In this section, we estimate the impact of expansionary QE and FG announcements on capital investment using an unbalanced panel of U.S. public firms and quarterly data over the period 2000-2018.<sup>39</sup> As in Chapter 2, we employ the panel VAR methodology developed by Holtz-Eakin et al. (1988).<sup>40</sup> To address potential endogeneity issues, all models are consistently estimated using a difference GMM estimator. Time-invariant fixed effects are removed by first differencing the model. The variables in differences are instrumented by the lagged values of the variables in levels (Abrigo and Love 2016, Arellano and Bond 1991, Holtz-Eakin et al. 1988, Roodman 2009).<sup>41</sup> For each model, all the variables are instrumented using

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<sup>39</sup> Following prior literature, we exclude financials and utilities (Pindado et al. 2011).

<sup>40</sup> See Chapter 2, section 2.2.1, for an analytical explanation of the panel VAR methodology. See the same section for the advantages of panel VAR models.

<sup>41</sup> First-differencing the variables mitigates potential problems of unit roots (Abrigo and Love 2016).

the same set of instruments, although each model contains a different set of instruments. Hansen's  $J$  statistic is estimated to test the joint validity of each proposed instrument set (Hansen 1982).

Particularly, the following reduced-form panel-VAR model is estimated:

$$I_{i,t} = \sum_{j=1}^p \beta_j I_{i,t-j} + \sum_{j=1}^p \gamma_j Q_{i,t-j} + \sum_{j=1}^p \delta_j CF_{i,t-j} + \sum_{j=1}^p \theta_j UMP_{t-j} + \omega_i + \nu_{i,t} \quad (3)$$

where  $t$  denotes year,  $i$  denotes firm, and  $p$  the lag order;  $I$  is investment;  $Q$  represents Tobin's  $q$ ;  $CF$  is a cash-flow variable;  $UMP$  is an indicator of the Federal Reserve's unconventional monetary-policy measures;  $\omega$  is a vector of firm-specific and industry-specific fixed effects;  $\nu$  is the serially-uncorrelated error term; and  $\beta, \gamma, \delta$  and  $\theta$  are matrices of coefficients capturing the marginal effects of the lagged variables on investment.

We measure investment as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter ( $I_{i,t}$ ) (Carpenter and Guariglia 2008). The lagged dependent variable ( $I_{i,t-1}$ ) captures the accelerator effect and the investment dynamics (Aivazian et al. 2005). The ratio of enterprise value in the quarter of observation to total assets proxies Tobin's  $q$  ( $Q_{i,t-1}$ ) (Pindado et al. 2011). Financial constraints are measured using a cash-flow estimate ( $CF_{i,t-1}$ ), calculated as after-tax profits plus depreciation normalized by gross fixed assets at the beginning of the quarter (Carpenter and

Guariglia 2008). The three variables enter all models in logarithmic and first difference form.<sup>42</sup>

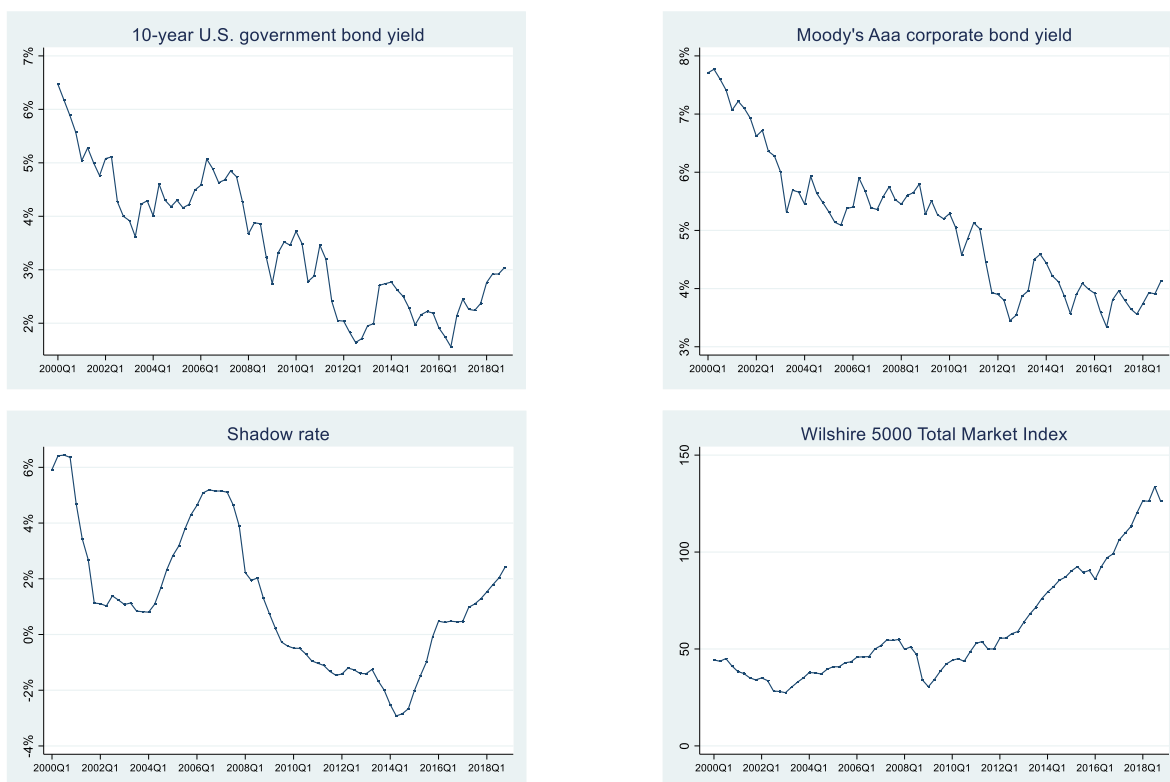
We use four different unconventional monetary-policy indicators. We draw upon the 10-year U.S. government bond yield ( $10YGB_t$ ) and Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ). Bernanke (2020) shows that unconventional monetary policy contributed to lowering both Treasury and corporate yields. We also employ the shadow rate ( $SR_t$ ) (Wu and Xia 2016) as “a summary measure of the stance of monetary policy, including nontraditional measures” (Bernanke 2020: p. 965). Finally, we use the Wilshire 5000 Total Market Index since there is ample evidence that unconventional monetary policy contributed to increasing stock prices ( $WI_t$ ) (Bernanke 2020). Figure 10 shows the evolution of these four monetary-policy indicators between 2000 and 2018, while Table 5 displays summary statistics for all the above variables.<sup>43</sup>

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<sup>42</sup> Observations below the 1st percentile and above the 99th percentile are removed. When applying the log-transformation, zero-valued observations become missing values. Nonetheless, this does not pose a problem since fewer than 0.9% of the observations for the three transformed variables have values of zero.

<sup>43</sup> All data were retrieved from the Federal Reserve Banks of St. Louis and Atlanta, and Eikon Reuters.

### 3. Unconventional monetary policy and capital investment in the aftermath of the Great Recession



**Fig. 10.** Evolution of the 10-year U.S. government bond yield (top left), Moody's seasoned Aaa corporate bond yield (top right), the shadow rate (bottom left), and the Wilshire Total Market Index (bottom right) over the period 2000Q1-2018Q4.

**Table 5 – Summary statistics**

Variable	Mean	Median	St. dev.	Maximum	Minimum	Observations
$I_{i,t}$	.03	.0171	.0444	.4330	0	42,151
$Q_{i,t}$	7.97	1.8	32.11	496.9	.5481	181,707
$CF_{i,t}$	-.5824	.0247	2.931	1.319	-38.47	40,979
$10YGB_t$	3.5	3.475	1.215	6.47	1.56	76
$AAA_t$	5.088	5.235	1.151	7.77	3.34	76
$SR_t$	1.198	1.051	2.434	6.439	-2.922	76
$WI_t$	59.85	49.85	27.95	133.75	27.46	76

This table provides summary statistics for investment ( $I_{i,t}$ ), Tobin's Q ( $Q_{i,t}$ ), cash flows ( $CF_{i,t}$ ), the 10-year U.S. government bond yield ( $10YGB_t$ ), Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ), the shadow rate ( $SR_t$ ), and the Wilshire 5000 Total Market Index ( $WI_t$ ). The sample comprises 5,048 U.S. publicly traded firms. Financials and utilities are excluded from the sample. The period covered spans 2000Q1 to 2018Q4.

#### 3.2.2. Identification strategy

The four selected indicators may be influenced by factors other than unconventional monetary policy. In order to isolate the effects of unconventional monetary-policy shocks on capital investment, we take two steps. First, we build two dummies and interact them with each of the monetary-policy indicators. The first dummy (*dummyQE*) takes the value 1 in the quarter when an expansionary QE announcement was made, and 0 otherwise. The second dummy (*dummyFG*) takes the value 1 when an expansionary FG announcement was made, and 0 otherwise.<sup>44</sup> All announcements were made between 2008Q4 and 2015Q1, a period of high EPU.<sup>45</sup> Second, we use the Cholesky decomposition and estimate orthogonalized impulse-response functions to test the responsiveness of capital investment to unconventional monetary-policy shocks, which are measured using the interaction terms described above.<sup>46</sup> A restriction is imposed so that investment reacts with a lag (Sims 1980).

Our identification strategy draws upon the implicit assumption that expansionary QE and FG announcements stimulated the issuance of long-term debt and stock, which was later used to fund new investments. Figure 11 displays the evolution of long-term borrowings (left)

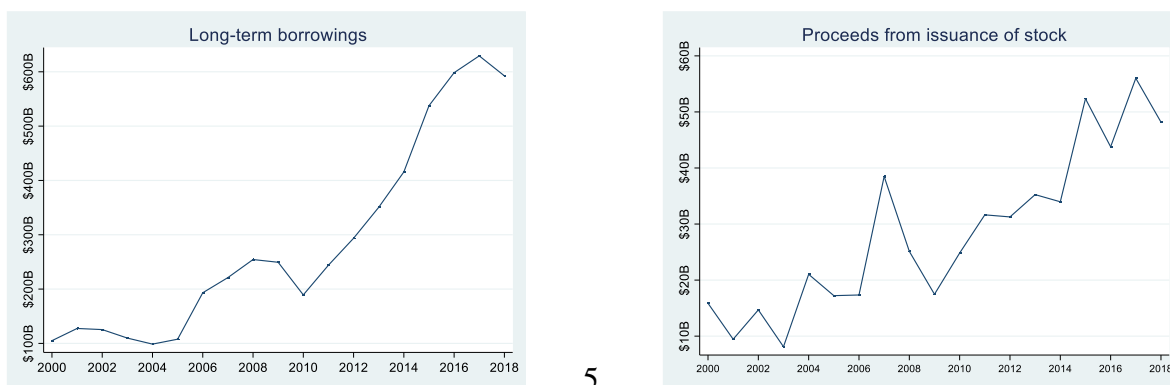
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<sup>44</sup> Expansionary QE announcements have been retrieved from [www.yardeni.com/chronology-of-feds-quantitative-easing/](http://www.yardeni.com/chronology-of-feds-quantitative-easing/). Expansionary FG announcements can be found at the Federal Reserve website (Board of Governors of the Federal Reserve System 2019).

<sup>45</sup> During this period, the monthly EPU index, which measures economic policy uncertainty, was, on average, 37% higher than that of the period 1985Q1-2008Q3. Similarly, the VIX index during the same period was, on average, 15% higher than between 1990Q1 and 2008Q3 (there is no data prior to 1990). The EPU index and the VIX index are positively correlated, although they differ in several aspects. For a detailed discussion of how the EPU index compares with the VIX index and other uncertainty measures, see Baker et al. (2016).

<sup>46</sup> To mitigate potential endogeneity problems, the interaction terms also enter the models in first-difference form.

and stock issuances (right) between 2000 and 2018 for our sample of firms. As shown, there was a substantial increase in both long-term borrowings and stock issuances from 2010 and 2009, respectively. This is in line with the hypothesis that unconventional monetary policy play an important role in fostering investment via lower bond yields and higher equity prices, which we test hereunder.



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**Fig. 11.** Evolution of long-term borrowings (left) and stock issuances (right) in our sample over the period 2000-2018.

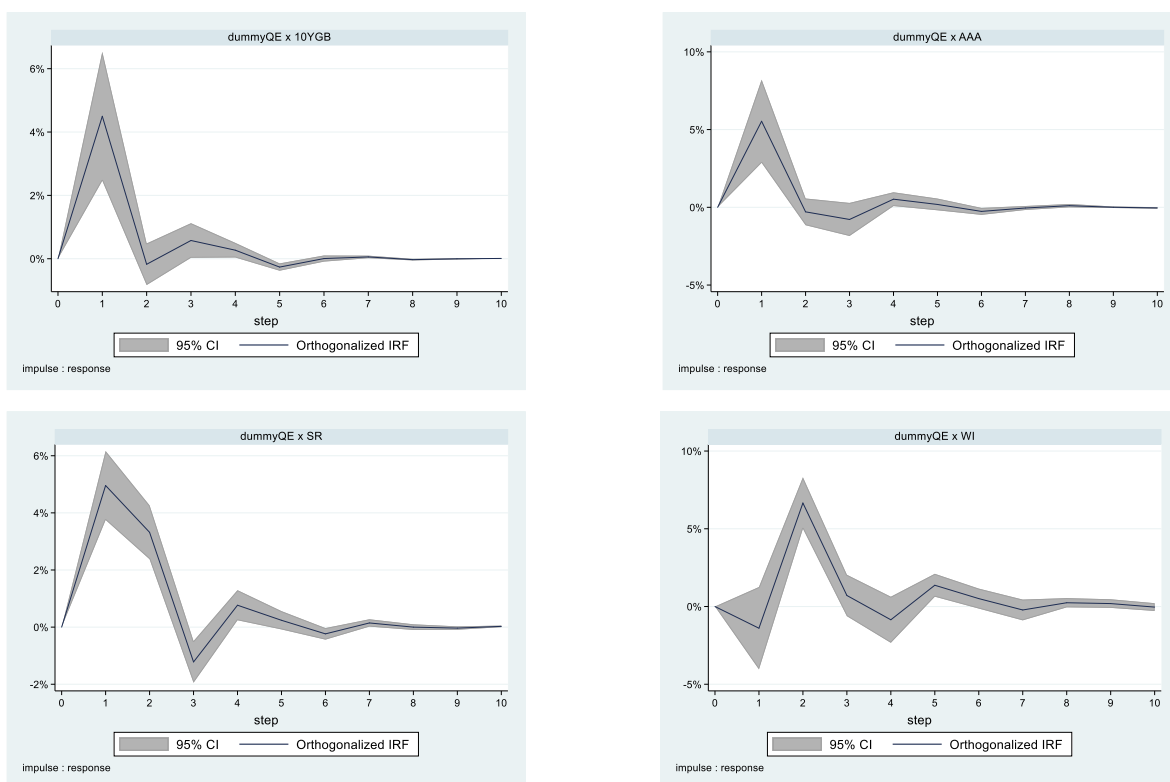
### 3.2.3. Full-sample results

Figure 12 shows the effects of expansionary QE announcements on capital investment.<sup>47</sup> A one-standard-deviation reduction in the 10-year U.S. government (Moody’s Aaa corporate bond yield) resulting from an expansionary QE announcement is associated with a 4.5% (5.54%) increase in capital investment. Similarly, an unconventional monetary-policy shock that reduces the shadow rate by one standard deviation as a result of an expansionary QE announcement is accompanied by 4.96% increase in capital investment. Finally, a one-

<sup>47</sup> Table H in Appendix A contains the estimated first-order, panel VAR models corresponding to Figure 12. Lag-selection criteria can be found in the same appendix, Table I. All models meet the stability condition. Stability tests can be found in Appendix A, Figure D.



standard-deviation increase in the Wilshire 5000 Total Market Index after an expansionary QE announcement is associated with a 6.66% hike in capital investment. Overall, these results seem to support **H5**.



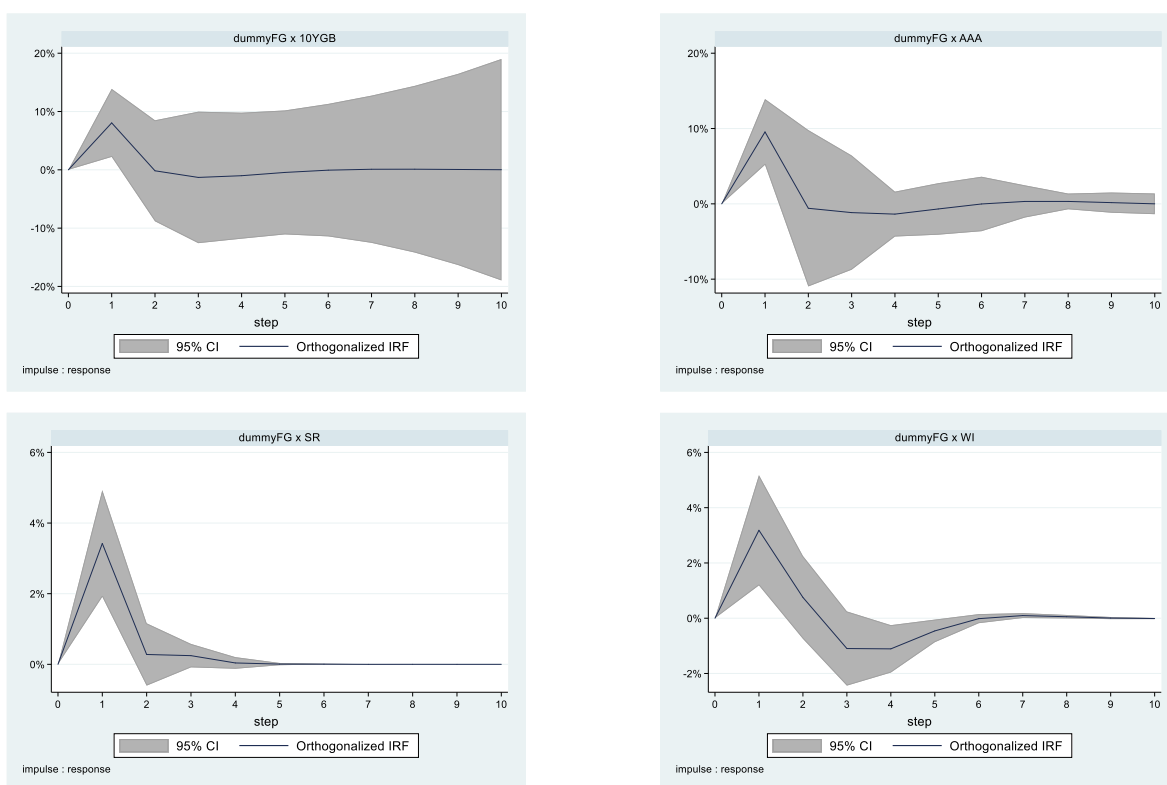
**Fig. 12.** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction of a dummy that takes the value 1 when an expansionary QE announcement was made ( $dummyQE$ ) and four unconventional monetary-policy indicators: the 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). The shaded area represents a 95% confidence interval.

Figure 13 shows the effects of expansionary FG announcements on capital investment.<sup>48</sup>

A one-standard-deviation decrease in the 10-year U.S. government bond yield (Moody's Aaa corporate bond yield) resulting from an expansionary FG announcement is accompanied

<sup>48</sup> Table J in Appendix A contains the estimated first-order, panel VAR models corresponding to Figure 12. Lag-selection criteria can be found in the same appendix, Table K. All models meet the stability condition. Stability tests can be found in Appendix A, Figure D.

by an 8.05% (9.55%) increase in capital investment. When considering the shadow rate as the unconventional monetary-policy indicator, results are similar: an unconventional monetary-policy shock in the shadow rate as a consequence of an expansionary FG announcement is associated with a 3.42% hike in capital investment. Lastly, a one-standard-deviation increase in the Wilshire 5000 Total Market Index resulting from an expansionary FG announcement is related to a 3.18% increase in capital investment. Overall, these results confirm **H6**.

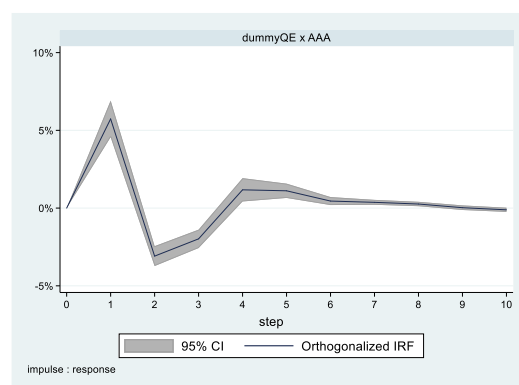
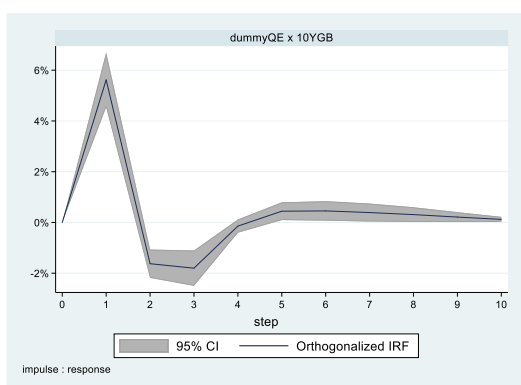


**Fig. 13** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when an expansionary FG announcement was made ( $dummyFG$ ) and four unconventional monetary-policy indicators: the 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). The shaded area represents a 95% confidence interval.

### 3.2.4. Robustness tests

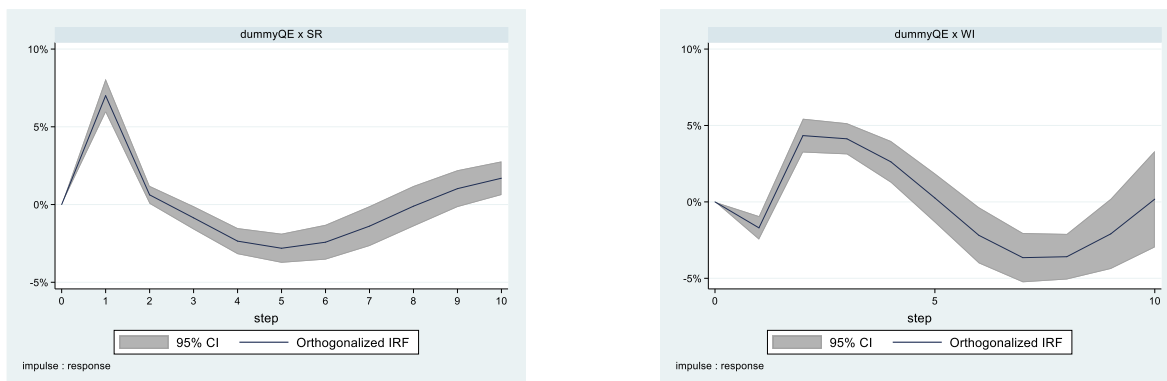
In order to test the robustness of our results, we consider two alternative specifications. First, we control for potential industry spillovers by adding the sum of capital expenditures for the whole sample lagged four quarters as a control variable and estimate orthogonalized impulse-response functions. Figures 14 and 15 show the effects on capital investment of expansionary QE and FG announcements, respectively.<sup>49</sup>

As shown, results are similar in sign and statistical significance, although there are some differences in magnitude. Specifically, the impact of expansionary FG announcements seems lower after controlling for industry spillovers, especially when using the 10-year U.S. government bond yield and the Wilshire 500 Total Market Index as unconventional monetary-policy indicators.

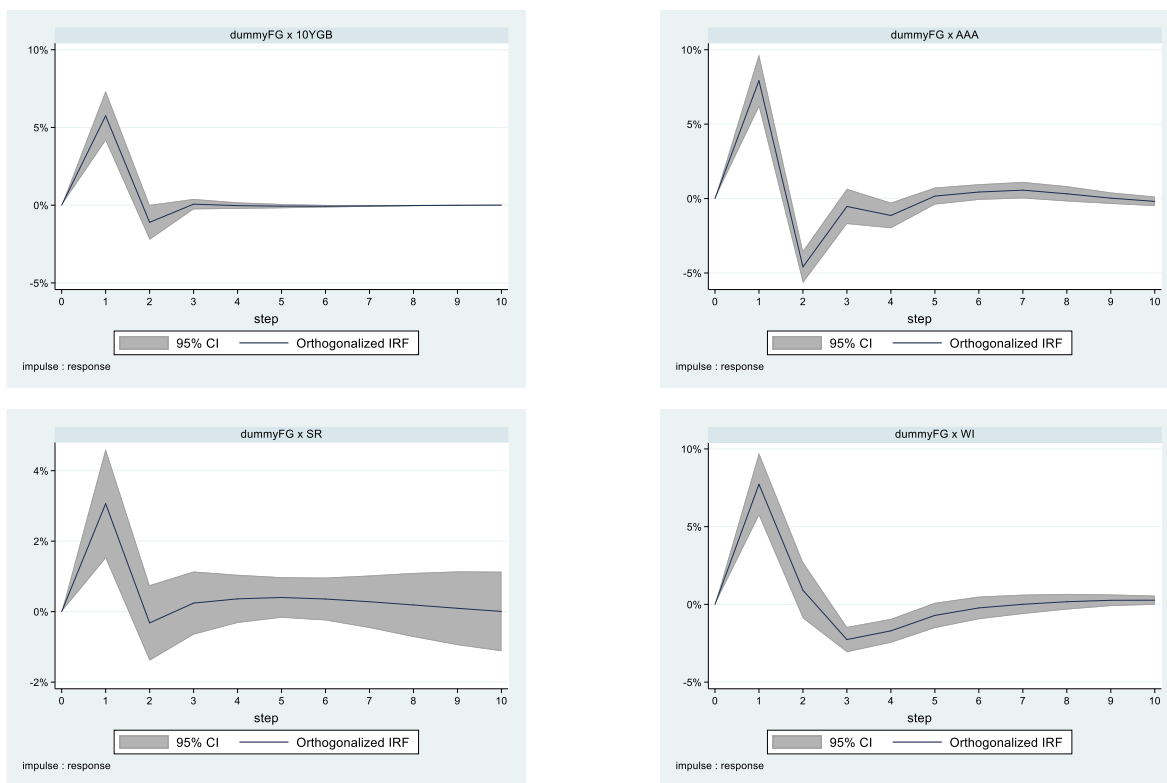



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<sup>49</sup> Tables L and N in Appendix A contain the estimated first-order, panel VAR models corresponding to Figures 14 and 15. Lag-selection criteria can be found in the same appendix, Tables M and O. All models meet the stability condition. Stability tests can be found in Appendix A, Figure E.

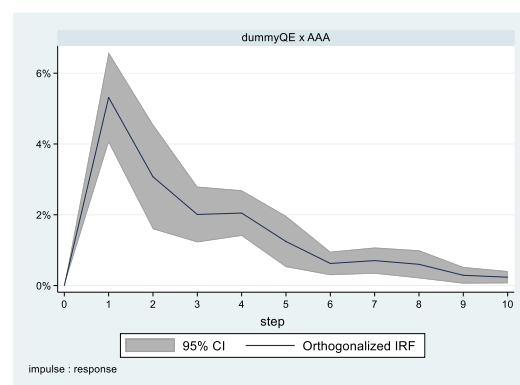
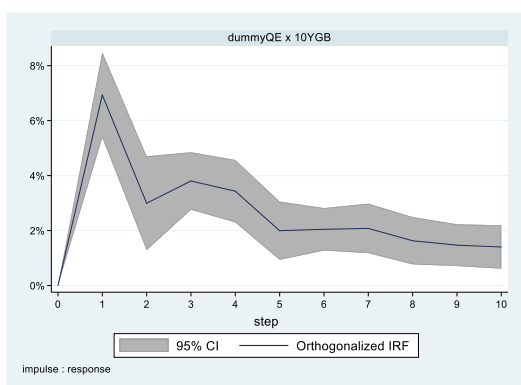


**Fig. 14.** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when an expansionary QE announcement was made ( $dummyQE$ ) and four unconventional monetary-policy indicators: 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). Industry spillovers are controlled for. The shaded area represents a 95% confidence interval.



**Fig. 15.** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when an expansionary FG announcement was made ( $dummyFG$ ) and four unconventional monetary-policy indicators: 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). Industry spillovers are controlled for. The shaded area represents a 95% confidence interval.

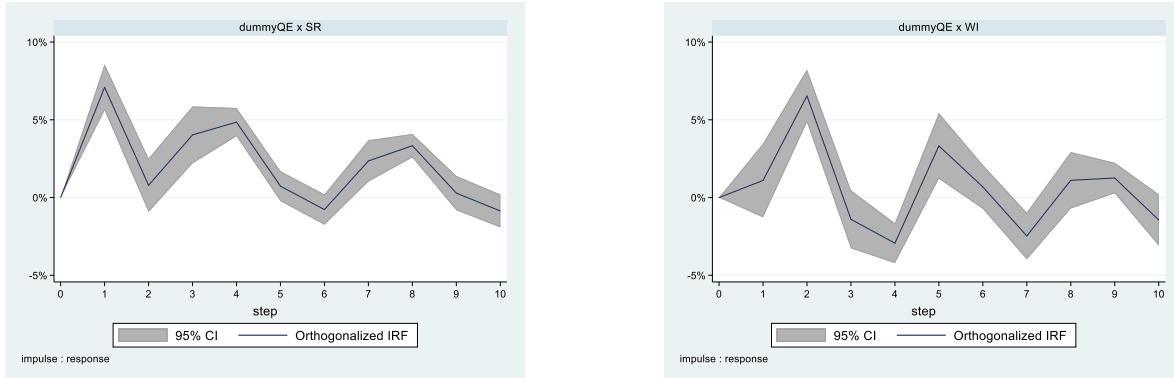
Second, we control for the term spread since unconventional monetary policy has a significant influence on the slope of the yield curve (Eberly et al. 2019). To do so, we add the spread between 10-year U.S. government bond yield and the 3-month U.S. Treasury Bill as a control variable and estimate orthogonalized impulse-response functions. The effects on capital investment of expansionary QE and FG announcements after controlling for the term spread can be found in Figures 16 and Figures 17, respectively.<sup>50</sup> Whereas QE announcements have a similar effect when compared to the baseline scenario, the impact of FG announcements on capital investment is substantially greater after controlling for the term spread for three of the unconventional monetary-policy indicators: the 10-year U.S. government bond yield, the shadow rate, and the Wilshire 5000 Total Market Index.



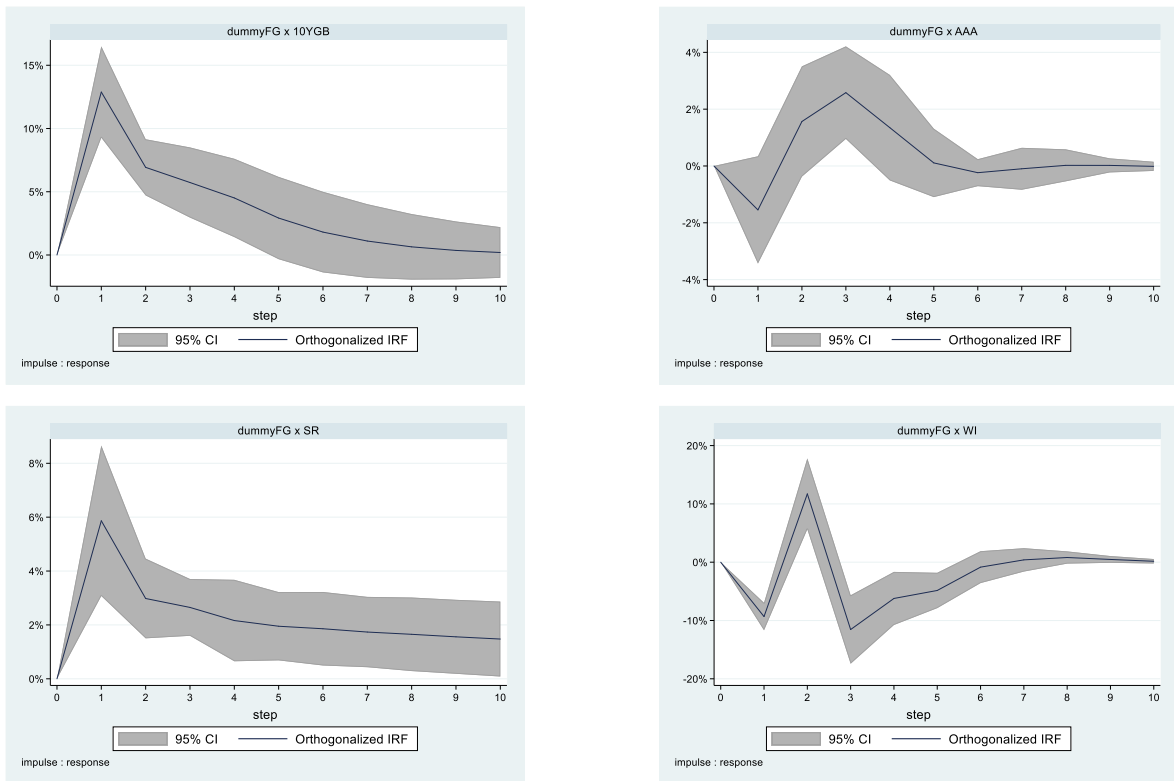

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<sup>50</sup> Tables P and R in Appendix A contain the estimated first-order, panel VAR models corresponding to Figures 16 and 17. Lag-selection criteria can be found in the same appendix, Tables Q and S. All models meet the stability condition. Stability tests can be found in Appendix A, Figure F.

### 3. Unconventional monetary policy and capital investment in the aftermath of the Great Recession



**Fig. 16.** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when an expansionary QE announcement was made ( $dummyQE$ ) and four unconventional monetary-policy indicators: 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). The term spread is controlled for. The shaded area represents a 95% confidence interval.



**Fig. 17.** Orthogonalized impulse-response functions (IRFs). Response of investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when an expansionary FG announcement was made ( $dummyFG$ ) and four unconventional monetary-policy indicators: 10-year U.S. government bond yield ( $10YGB_t$ ; top left); Moody's seasoned Aaa corporate bond yield ( $AAA_t$ ; top right); the shadow rate ( $SR_t$ ; bottom left); and the Wilshire 500 Total Market Index ( $WI_t$ ; bottom right). The term spread is controlled for. The shaded area represents a 95% confidence interval.

### 3.2.5. *Asymmetries at the firm level*

So far, the evidence suggests that unconventional monetary policy has a positive impact on capital investment, encouraging firms to undertake new investments. Next, we aim to elucidate whether this impact is uniform across firms.

According to the real options literature, three specific characteristics may make the impact of monetary policy asymmetric at the firm level in contexts of high EPU: investment irreversibility, operational inflexibility, and opportunity costs (Bontempi et al. 2009, Grullon et al. 2012, Gulen and Ion 2016). We measure investment irreversibility as net property, plant and equipment over total assets ( $PPE_{i,t}$ ) (Gulen and Ion 2016). The rationale is that investments in physical assets tend to: 1) require substantial upfront costs; and 2) be specific to their line of business. Operational inflexibility ( $OF_{i,t}$ ) is calculated as fixed costs over sales (Agrawal and Hall 2014, Jiang et al. 2006). Firms with high fixed costs will find it more difficult to expand or contract operations in response to shifts in economic conditions. Finally, opportunity costs resulting from the loss of competitive advantages are measured using the price-cost margin ( $PCM_{i,t}$ ) (Bontempi et al. 2009, Domowitz et al. 1986). Firms with high price-cost margins (i.e., high market power) face lower opportunity costs since their competitive position is less vulnerable to preemptive actions by rivals. Table 6 displays summary statistics for all the above variables.<sup>51</sup>

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<sup>51</sup> Observations below the 1st percentile and above the 99th percentile have been removed.

**Table 6 – Summary statistics**

Variable	Mean	Median	St. dev.	Maximum	Minimum	Observations
$PPE_{i,t}$	.2515	.153	.2586	.9553	0	187,100
$OF_{i,t}$	1.89	.3053	7.72	105.6	.0178	155,624
$PCM_{i,t}$	.4329	.4169	.3298	1.225	-2.224	144,995

This table provides summary statistics for plant, property, and equipment over total assets ( $PPE_{i,t}$ ), fixed costs over sales ( $OF_{i,t}$ ), and the price-cost margin ( $PCM_{i,t}$ ). The sample comprises 5,048 U.S. publicly traded firms. Financials and utilities are excluded from the sample. The period covered spans 2000 to 2018.

In order to determine the moderating role of investment irreversibility, operational inflexibility, and opportunity costs in the relationship between unconventional monetary policy and capital investment, we proceed as follows. First, we build a dummy that takes the value 1 when either an expansionary QE or FG announcement was made, and 0 otherwise (*dummyQEEFG*) and interact it with Moody's seasoned Aaa corporate bond yield. We use this corporate bond yield as our preferred unconventional monetary-policy indicator since there is a strong relationship between corporate yields and capital investment (Giambona et al. 2020). Furthermore, the evidence suggests that unconventional monetary policy was effective at lowering corporate bond yields in the aftermath of the Great Recession (Kuttner 2018). Second, we divide the sample for each moderating variable using a dummy that takes the value 1 when the observation is above the industry median in each quarter, and 0 otherwise and estimate orthogonalized impulse-response functions to elucidate the asymmetric impact of unconventional monetary-policy shocks on capital investment. A short-run restriction is imposed so that investment reacts with a lag to unconventional monetary-policy shocks (Sims 1980).



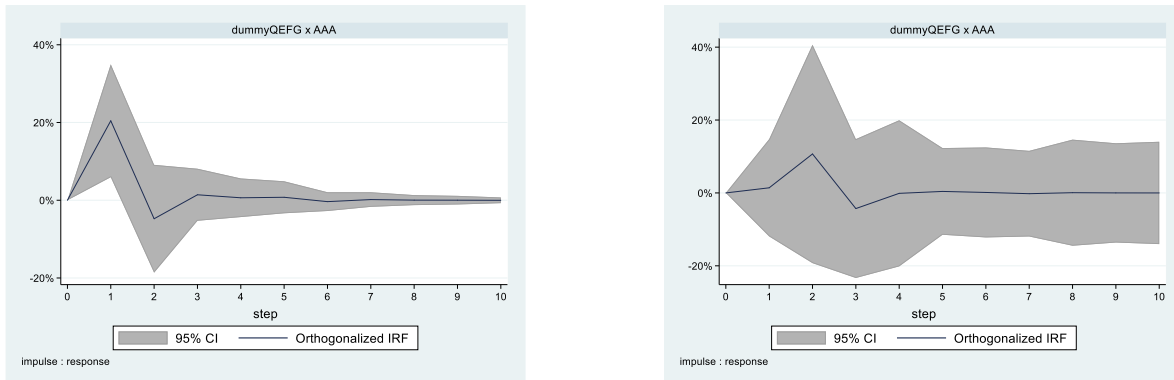
Results can be found in Figures 18 to 20.<sup>52</sup> In all figures, right (left) panels show the effect on the subsample where the option value to wait is assumed to be higher (lower) and, therefore, the impact of expansionary QE and FG announcements should be lower (higher). Figures 18 and 19 display the effects on capital investment of a one-standard-deviation shock on the interaction between Aaa Moody's corporate bond yield and the dummy defined above (*dummyQEFG*) for firms with low (left) and high (right) levels of investment irreversibility and operational inflexibility, respectively. Results seem to confirm **H7** and **H8**: expansionary QE and FG announcements are less effective in stimulating investment of firms with higher investment irreversibility and higher operational inflexibility. Specifically, an unconventional monetary-policy shock is associated with a 20.45% increase in capital investment of firms with lower levels of investment irreversibility, whereas it has no effect on capital-intensive firms, as shown by the fact that the confidence intervals include the zero line (Abrigo and Love 2016). Similarly, flexible firms are more impacted by unconventional monetary-policy shocks than inflexible firms, although the difference is barely noticeable. Indeed, firms with lower operational inflexibility increase their investment by 4.8% after a shock, as opposed to 4.13% for operationally inflexible firms.

Finally, Figure 20 shows the impact on capital investment of a one-standard-deviation shock on the interaction variable for firms with low (left) and high market power (right). Results indicate that firms with high market power are less responsive to unconventional

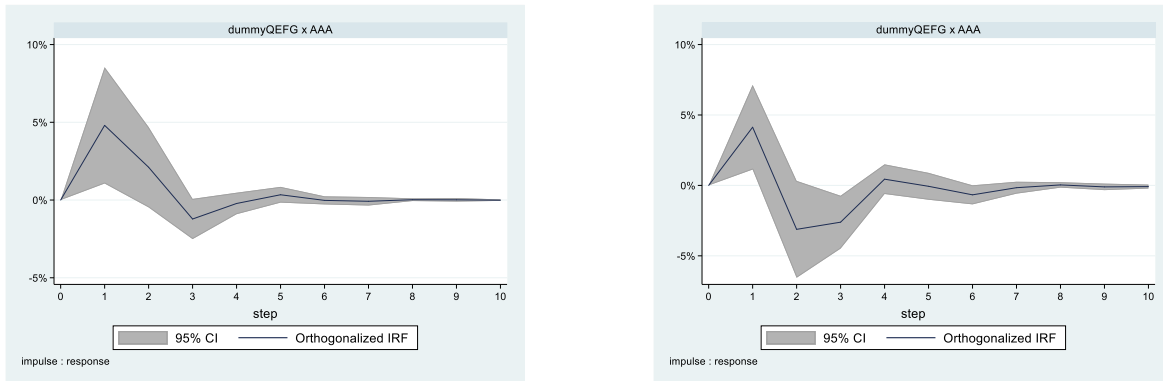
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<sup>52</sup> Table T in Appendix A contains the estimated first-order, panel VAR models corresponding to Figures 18 and 20. Lag-selection criteria can be found in the same appendix, Table U. All models meet the stability condition. Stability tests can be found in Appendix A, Figure G.

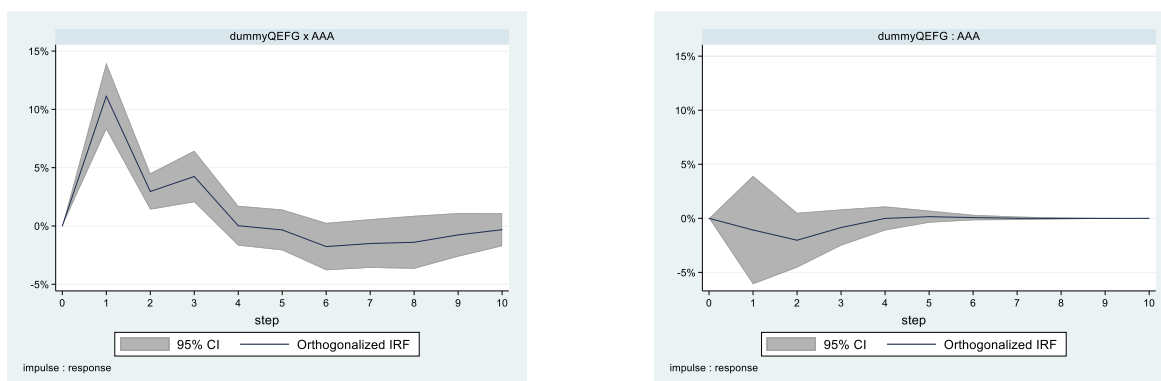
monetary-policy shocks than low-market-power firms, which is line with **H9**. Specifically, an unconventional monetary-policy shock is associated with an 11.14% increase in capital investment of firms with low market power, whereas the same shock has no impact on high-market-power firms.



**Fig. 18.** Orthogonalized impulse-response functions (IRFs). Response of capital investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when either an expansionary QE or a FG announcement was made (*dummyQEFG*) and Moody’s Aaa corporate bond yield for firms with low (left) and high (right) investment irreversibility.



**Fig. 19.** Orthogonalized impulse-response functions (IRFs). Response of capital investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when either an expansionary QE or a FG announcement was made (*dummyQEFG*) and Moody’s Aaa corporate bond yield for firms with low (left) and high (right) operational inflexibility.



**Fig. 20.** Orthogonalized impulse-response functions (IRFs). Response of capital investment to a one-standard-deviation shock to the interaction between a dummy that takes the value 1 when either an expansionary QE or a FG announcement was made (*dummyQEFG*) and Moody’s Aaa corporate bond yield for firms with low (left) and high (right) market power.

### 3.3. In a nutshell

In the aftermath of the Great Recession, the Federal Reserve was compelled to resort to two unconventional monetary-policy tools: quantitative easing and forward guidance. In this chapter, we analyze the effectiveness of these tools in stimulating investment. We find that expansionary QE and FG announcements have a positive but uneven impact on capital investment. Specifically, capital investment is less responsive to unconventional monetary-policy shocks for firms with higher levels of investment irreversibility, operational inflexibility, and market power.

## **Chapter 4. Monetary policy, economic policy uncertainty, and R&D investment**

As shown in the previous chapters, the relationship between investment, uncertainty, and monetary policy has been the subject of research by economists for decades. The existing literature suggests that both firm-level uncertainty and EPU discourage capital investment by increasing the value of the option to invest in the future (Baker et al. 2016, Bertola 1998, Bloom et al. 2007, Dixit and Pindyck 1994, Gulen and Ion 2016, Henry 1974, Suh and Yang 2021). Similarly, contractionary monetary policy based on fine-tuning the policy rate tends to have a depressing effect on capital investment (Bernanke and Blinder, 1992; Boivin et al., 2010; Gertler and Gilchrist, 1994; Givens and Reed, 2018; Romer and Romer, 1990). Some recent papers have also examined the joint effect of monetary policy and EPU on capital investment (Aastveit et al. 2017, de la Horra et al. 2021).

Interestingly, R&D investment may react differently to EPU and monetary policy. According to the real options approach, an investment in an R&D project may result in the acquisition of new knowledge or a new technology that provides firms with the option (but not the obligation) to undertake a new investment in the future (Dixit and Pindyck 1995). An increase (decrease) in uncertainty and interest rates enhances (reduces) the value of growth options emerging from R&D projects, encouraging (discouraging) firms to invest in R&D (Kester 1984, Mitchell and Hamilton 1988). In this chapter, we analyze the relationship between R&D investment, EPU, and monetary policy through the lens of the real options approach. Using a panel of U.S. public firms over the period 2000-2019, we find that higher

(lower) EPU and contractionary (expansionary) monetary policy exert a positive (negative) and significant effect on R&D investment. Furthermore, the interaction of EPU and the monetary-policy rate has a negative influence on R&D investment.

The remainder of the chapter is structured as follows. Section 4.1 presents the theoretical framework and research hypotheses. Section 4.2 shows the empirical methodology and results. Lastly, Section 4.3 concludes this chapter with a summary of the main findings.

#### **4.1. Model and hypotheses**

According to the real options approach, an investment in an R&D project is similar to the acquisition of a call option (Dixit and Pindyck 1995, Kester 1984, Mitchell and Hamilton 1988). When an investor purchases a call option on a stock, they acquire the right (but not the obligation) to buy the underlying financial asset at a future date. Similarly, a firm that undertakes an R&D investment acquires a call option on real assets (i.e., a strategic growth option). R&D projects result in intangible assets (e.g., knowledge or innovation capabilities) that allow firms to undertake new investments that otherwise would not be available. In this sense, R&D projects can be considered platforms that help firms to take advantage of future growth opportunities.

The impact of uncertainty on investment decisions depends on the nature of investments: whereas it tends to have a depressing effect on one-step full scale capital investments (Bloom et al. 2007), an increase in uncertainty may prompt investments in growth options such as R&D projects (Dixit and Pindyck 1995, Estrada et al. 2010). Higher uncertainty increases both potential gains and losses from immediate and irreversible full-scale investments,

raising their risk adjusted cost of capital and lowering the present value of expected cash flows. However, the value of an R&D investment is expected to increase with uncertainty in the same way as the value of a financial call option is positively affected by uncertainty. This positive relationship stems from the fact that higher uncertainty increases the probability of realizing large gains from investing in subsequent underlying projects, but does not increase expected losses since an initial investment in R&D does not compel firms to undertake further investments (Mitchell and Hamilton 1988, Tiberius et al. 2021).

Analytically, this result can be easily deduced from the partial derivatives of the value of a call option. According to Black and Scholes (1973) and Merton (1973), the present value ( $C_0$ ) of a European call option at time  $t = 0$  is:

$$C_0 = S_0 \cdot e^{-qT} N(d_1) - X \cdot e^{-rT} N(d_2) \quad (4)$$

where  $S_0$  represents the present value of the underlying asset;  $T$  and  $X$  are the option's time to maturity and exercise price, respectively;  $r$  is the risk-free interest rate;  $q$  and  $\sigma$  are, respectively, the cash-flow yield and the volatility of the underlying asset;  $N(\cdot)$  is the cumulative normal distribution, and, finally,  $d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left(r - q + \frac{\sigma^2}{2}\right) \cdot T}{\sigma \cdot \sqrt{T}}$ , and  $d_2 = d_1 - \sigma \cdot \sqrt{T}$ .

Assuming that  $S$ ,  $X$ ,  $q$ , and  $r$  are independent of  $\sigma$ , the partial derivative of Eq. (4) with respect to the volatility of the underlying asset ( $\sigma$ ) is:

$$\frac{\partial C_0}{\partial \sigma} = S_0 \cdot e^{-qT} \cdot n(d_1) \cdot \frac{\partial d_1}{\partial \sigma} - X \cdot e^{-rT} \cdot n(d_2) \cdot \frac{\partial d_2}{\partial \sigma} \quad (5)$$

Since  $n(d_1) = \frac{1}{\sqrt{2\pi}} e^{-\frac{d_1^2}{2}}$  and  $n(d_2) = n(d_1) \cdot \frac{S}{X} \cdot e^{(r-q) \cdot T}$ , and given that  $\frac{\partial d_1}{\partial \sigma} = \frac{-\ln(\frac{S}{X}) - (r-q) \cdot T}{\sigma^2 \sqrt{T}} + \frac{1}{2} \sqrt{T} = \frac{\partial d_2}{\partial \sigma} + \sqrt{T}$ , we obtain:

$$\frac{\partial C_0}{\partial \sigma} = S_0 \cdot e^{-qT} n(d_1) \cdot \sqrt{T} \quad (6)$$

where  $n(\cdot)$  is the normal probability density function and, therefore,  $\frac{\partial C_0}{\partial \sigma}$  is always positive.

The underlying asset of an R&D growth option is the capital investment that the firm will undertake provided that the R&D project yields positive results. The volatility of the underlying investment (i.e., the variability of the potential cash flows it is expected to generate in the future; Santiago and Vakili, 2005) will thus be affected by both endogenous and exogenous uncertainty. Endogenous uncertainty can be partially reduced by the outcome of the R&D investment. In contrast, exogenous uncertainty (e.g., the one resulting from the economic policy carried out by governments) cannot be dealt with by the action of individual firms (Estrada et al. 2010, Folta and O'Brien 2004). Accordingly, we state the following hypothesis:

**H10.** Higher (lower) EPU exerts a positive (negative) influence on R&D investment.

Similarly, the monetary-policy rate may also have a positive influence on R&D investment. Capital expenditures are negatively affected by interest rates as the opportunity cost of one-step full scale investments increases when interest rates rise. In contrast, R&D outcomes are growth options to undertake new capital investments in the future. Since growth options are postponed investments, higher interest rates decrease the present value of their

exercise prices (future outlays) (Kester 1984). As a result, an increase in the monetary-policy rate should have a positive impact on R&D investment. Analytically, assuming that  $S$ ,  $X$ ,  $q$  and  $\sigma$  are independent of  $r$ , and taking the first-order partial derivative of Eq. (4) with respect to the risk-free rate ( $r$ ), we obtain:

$$\frac{\partial c_0}{\partial r} = S_0 \cdot e^{-qT} \cdot n(d_1) \cdot \frac{\partial d_1}{\partial r} + T \cdot X \cdot e^{-rT} \cdot N(d_2) - X \cdot e^{-rT} \cdot n(d_2) \cdot \frac{\partial d_2}{\partial r} \quad (7)$$

Given that  $\frac{\partial d_1}{\partial r} = \frac{\partial d_2}{\partial r} = \frac{\sqrt{T}}{\sigma}$ , it follows that:

$$\frac{\partial c_0}{\partial r} = T \cdot X \cdot e^{-rT} N(d_2) \quad (8)$$

which is always positive.

This leads us to posit the following hypothesis:

**H11.** Contractionary (expansionary) monetary policy exerts a positive (negative) influence on R&D investment.

Finally, a simultaneous increase (decrease) in EPU and the monetary-policy rate may have an additional effect on R&D investment. To elucidate such a joint effect, we take second-order mixed partial derivatives of Eq. (4) with respect to  $\sigma$  and  $r$ :

$$\frac{\partial^2 c}{\partial r \partial \sigma} = \frac{\partial}{\partial \sigma} [T \cdot X \cdot e^{-rT} N(d_2)] = T \cdot X \cdot e^{-rT} \cdot n(d_2) \cdot \frac{\partial d_2}{\partial \sigma} \quad (9)$$

Given that  $\frac{\partial d_2}{\partial \sigma} = \frac{-\ln(\frac{S}{X}) - (r-q) \cdot T}{\sigma^2 \sqrt{T}} - \frac{1}{2} \sqrt{T}$ , it follows that:

$$\frac{\partial^2 c}{\partial r \partial \sigma} = T \cdot X \cdot e^{-rT} \cdot n(d_2) \cdot \left[ \frac{-\ln(\frac{S}{X}) - (r-q) \cdot T}{\sigma^2 \sqrt{T}} - \frac{1}{2} \sqrt{T} \right] \quad (10)$$



or

$$\frac{\partial^2 c}{\partial r \partial \sigma} = -T \cdot X \cdot e^{-rT} \cdot n(d_2) \cdot \frac{d_1}{\sigma} \quad (11)$$

which will be negative as long as  $\frac{S_0}{X} > e^{-[\frac{1}{2}\sigma^2 + (r-q)] \cdot T}$ . This condition holds for R&D projects that are not deeply out of the money. Since out-the-money R&D projects are less likely to be undertaken, the negative impact is expected to predominate. Accordingly, we state our last hypothesis:

**H12.** The interaction between EPU and the monetary-policy rate exerts a negative influence on R&D investment.

## 4.2. Empirical analysis

### 4.2.1. Data and methodology

We build a database comprising 8,472 U.S. public firms for the period 2000-2019. Our sample covers U.S. companies filing with the Securities and Exchange Commission except financial firms.<sup>53</sup> Two different types of data are used in our empirical analysis. First, we draw upon firm-level accounting data from Refinitiv Eikon. Second, macroeconomic variables are retrieved from Economic Policy Uncertainty and the Federal Reserve Bank of St. Louis.<sup>54</sup>

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<sup>53</sup> Financial firms correspond to Thomson Reuters Business Classification codes 5510-5560.

<sup>54</sup> Sources: <http://policyuncertainty.com/> and <https://fred.stlouisfed.org/>.

In order to test the impact of EPU and the monetary-policy rate on R&D investment, we propose a panel-data model that allows unobserved heterogeneity to be controlled for. Our baseline specification is as follows:

$$RD_{i,t} = \beta_1 + \beta_2 U_t + \beta_3 MPR_t + \beta_4 (U_t * MPR_t) + \boldsymbol{\theta}' \mathbf{X}_{i,t} + \omega_i + \mu_t + v_{i,t}, \quad (8)$$

where  $i$  denotes the firm;  $t$  denotes the year;  $RD$  represents R&D investment;  $U$  is EPU;  $MPR$  is the monetary-policy rate;  $\mathbf{X}$  is a vector of control variables at the firm level;  $\boldsymbol{\beta}' = (\beta_1 \ \beta_2 \ \beta_3 \ \beta_4)$  and  $\boldsymbol{\theta}'$  are parameter vectors;  $\omega$  and  $\mu$  are firm and time fixed effects, respectively; and  $v$  is the error term satisfying classical panel data model assumptions.

We use three different proxies to measure R&D investment. The first ( $RD1_{i,t}$ ) is the natural logarithm of R&D investment (Cho and Lee 2020, Czarnitzki and Toole 2011, 2013). The second measure is R&D investment over total investment ( $RD2_{i,t}$ ), where total investment is defined as capital expenditures plus R&D investment (Peia and Romelli 2020). Finally, R&D investment scaled by total assets ( $RD3_{i,t}$ ) is our last proxy for the dependent variable (Zhang et al. 2020). EPU ( $U_t$ ) is measured using the natural logarithm of the EPU index (Baker et al. 2016). The monetary-policy rate ( $MPR_t$ ) is proxied by the fed funds rate (Bernanke and Blinder 1992, Zhang et al. 2020). Following Peia and Romelli (2020), our model includes five firm-level control variables: total liabilities over total assets ( $Leverage_{i,t}$ ), the natural logarithm of sales ( $Sales_{i,t}$ ), the natural logarithm of total assets ( $TA_{i,t}$ ), working capital normalized by total assets ( $WC_{i,t}$ ), and capital expenditures scaled by total assets ( $Capex_{i,t}$ ).

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Gulen and Ion (2016) suggest that introducing time fixed effects in a model with the EPU index would absorb all the explanatory power of the uncertainty variable. As a result, our model does not include time fixed effects. However, we still need to control for macroeconomic forces. In order to do so, we follow Gulen and Ion (2016) and introduce the growth rate of real GDP in our model ( $GDP_t$ ). Table 7 shows the descriptive statistics for all the variables.

**Table 7 – Summary statistics**

<b>Variable</b>	<b>Mean</b>	<b>Median</b>	<b>St. dev.</b>	<b>Maximum</b>	<b>Minimum</b>	<b>Observations</b>
$RD1_{i,t}$	8.853	9.036	2.48	14.952	1.946	31,412
$RD2_{i,t}$	.5509	.06514	.03849	1	0	38,817
$RD3_{i,t}$	.1942	.0392	.4777	5.516	0	41,425
$U_t$	125.73	133.304	32.294	188.696	67.136	20
$MPR_t$	1.784	1.238	1.862	6.236	.0892	20
$Leverage_{i,t}$	2.06	.5534	7.837	112.6	.0016	72,699
$Sales_{i,t}$	11.302	11.845	3.42	17.738	1.609	64,279
$TA_{i,t}$	11.095	11.575	3.675	17.845	1.099	72,979
$WC_{i,t}$	-1.227	.1609	7.65	.95	-110.857	68,327
$Capex_{i,t}$	.0472	.0244	.068	.5238	0	69,648
$GDP_t$	2.105	2.29	1.429	4.13	-2.54	20

This table provides summary statistics for the following variables: the natural logarithm of R&D investment ( $RD1_{i,t}$ ), R&D investment over total investment ( $RD2_{i,t}$ ), R&D investment over total assets ( $RD3_{i,t}$ ), the EPU index ( $U_t$ ), the fed funds rate ( $MPR_t$ ), total liabilities over total assets ( $Leverage_{i,t}$ ), the natural logarithm of sales ( $Sales_{i,t}$ ), the natural logarithm of total assets ( $TA_{i,t}$ ), working capital over total assets ( $WC_{i,t}$ ), capital expenditures over total assets ( $Capex_{i,t}$ ), and the growth rate of real GDP ( $GDP_t$ ). Observations below the 1<sup>st</sup> percentile and above the 99<sup>th</sup> percentile have been removed for all variables except for  $U_t$ ,  $MPR_t$ , and  $GDP_t$ . The sample comprises 8,472 U.S. public firms. Financials are excluded from the sample. The period covered spans 2000 to 2019.

#### 4.2.2. Results

Based on Eq. (8), we estimate three different models using each of the proxies for R&D investment. The estimation is performed using a within or fixed-effects estimator and Huber-White robust standard errors to overcome problems of heteroskedasticity (De Bandt and Davis 2000, Davis and Karim 2019).<sup>55</sup> A wide array of controls is introduced in the three models, including firm-level variables, a macroeconomic variable, and firm fixed effects.

Results can be found in Table 8. EPU ( $U_t$ ) is positive and highly significant in the three models, which seems to support **H10**: higher (lower) EPU increases (decreases) the value of R&D growth options, encouraging firms to undertake R&D investments. Our results align with those of Vo and Le (2017), who find a positive relationship between uncertainty and R&D investment. Similarly, contractionary (expansionary) monetary policy ( $MPR_t$ ) seems to have a positive (negative) impact on R&D investment as stated by **H11**.<sup>56</sup> These results are analogous to those in Dongyang et al. (2020), who show that U.S. contractionary monetary policy has a positive influence on the R&D investment of Chinese firms. Finally, the negative and significant coefficient of the interaction term supports **H12**.<sup>57</sup> This result suggests that when high EPU and contractionary monetary-policy rate concur, the individual effect of these variables is partially offset. Although statistically significant, the economic relevance of the

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<sup>55</sup> We choose a fixed-effects specification over a random-effects model according to the Hausman test (Hausman 1978), which can be found in Appendix A, Table V.

<sup>56</sup> Note that  $MPR_t$  is positive but insignificant in the model explaining  $RD2_{i,t}$ . This might be due to the fact that the denominator of  $RD2_{i,t}$  is also including investments in growth options different from R&D projects.

<sup>57</sup> This effect is not significant when using  $RD2_{i,t}$  as a proxy for R&D investment. As in the previous footnote, the reason might be that the denominator of  $RD2_{i,t}$  is capturing investments in growth options other than R&D projects.

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interaction effect is low compared to the direct effect of EPU and the monetary-policy rate on R&D investment.

**Table 8 – Panel data regressions on R&D determinants**

Dependent variable:	$RD1_{i,t}$	$RD2_{i,t}$	$RD3_{i,t}$
$U_t$	.2260*** (.031)	.0216*** (.0063)	.0764*** (.0109)
$MPR_t$	.1688*** (.0494)	.0065 (.0103)	.0922*** (.0167)
$U_t * MPR_t$	-.0384*** (.0108)	-.0021 (.0023)	-.0205*** (.0036)
Firm fixed effects	Yes	Yes	Yes
Macroeconomic controls	Yes	Yes	Yes
Firm-level controls	Yes	Yes	Yes
F-Statistic	323.75***	109.21***	36.7***
Within R-squared	.4098	.1571	.122
Observations	26,270	33,187	33,999

This table displays the estimates of Eq. (6) using a fixed-effects estimator with a panel comprising 8,472 US firms during 2000-2019. Three different proxies are used as dependent variables: the natural logarithm of R&D investment ( $RD1_{i,t}$ ), R&D investment over total investment ( $RD2_{i,t}$ ), and R&D investment over total assets ( $RD3_{i,t}$ ). All models include the growth rate of real GDP to control for macroeconomic forces ( $GDP_t$ ) and five firm-level control variables: total liabilities over total assets ( $Leverage_{i,t}$ ), the natural logarithm of sales ( $Sales_{i,t}$ ), the natural logarithm of total assets ( $TA_{i,t}$ ), working capital normalized by total assets ( $WC_{i,t}$ ), and capital expenditures over total assets ( $Capex_{i,t}$ ). \*\*\* indicates statistical significance at a 1% level. Huber-White standard errors are reported in parentheses.

### 4.3. In a nutshell

In this chapter, we analyze the impact of EPU and monetary policy on R&D investment through the lens of the real options approach. The main conclusion is optimistic: increasing EPU and contractionary monetary policy do not deter corporate investment in R&D. On the contrary, we find that they exert a positive influence that is only partially offset when both EPU and monetary-policy rate grow together. However, no less noteworthy is the other side

of the lesson: an expansionary monetary policy aimed at encouraging corporate investment is likely to discourage innovation, particularly if served with decreasing EPU.

## **Chapter 5. Concluding remarks, policy implications, and future research**

This Ph.D. dissertation investigates the effects of monetary policy and EPU on corporate investment in both capital assets and R&D. In order to carry out this task, we draw upon four strands of the literature, namely capital investment under uncertainty, the effects of conventional monetary policy on the real economy, the impact of unconventional monetary policy in the aftermath of the Great Recession, and R&D investment in the context of the real options approach. Based on this literature, three research gaps are identified and addressed in Chapters 2, 3, and 4.

Chapter 2 investigates how policy-rate-based monetary policy affects capital investment in contexts high and low EPU. Using a panel of U.S. firms, we find that corporate investment is less sensitive to expansionary monetary-policy shocks when EPU increases. We also show that the impact of conventional monetary policy on capital investment is asymmetric at the firm level. Concretely, in the presence of high EPU, firms with higher levels of investment irreversibility, operational inflexibility, and market power are less responsive to expansionary monetary policy.

Chapter 3 looks into the effects of unconventional monetary policy in the aftermath of the Great Recession in the U.S. Particularly, we analyze the influence of expansionary QE and FG announcements on capital investment. We find that both unconventional monetary-policy tools were effective in fostering corporate investment. In addition, we show that the effects of QE and FG are not uniform across firms: firms with higher investment

irreversibility, operational inflexibility, and market power are less affected by unconventional monetary-policy shocks.

Chapter 4 explores the connections between monetary policy, EPU, and R&D investment. Based on the Black-Scholes-Merton option-pricing model, we develop three research hypotheses and test them empirically using a fixed-effects model. We find that both EPU and contractionary monetary policy have a positive impact on R&D investment. However, the interaction between EPU and the monetary-policy rate exerts a negative influence on innovation investments, partially offsetting the positive impact of each variable alone.

Several policy implications can be drawn from our findings. First, given the importance of EPU to economic activity and, more specifically, to capital investment, political authorities should commit themselves to maintaining political stability and undertaking predictable economic policies in order to prevent uncertainty from rising, particularly in moments of economic turmoil. Second, central banks should focus their efforts on reducing uncertainty, as the transmission mechanisms of conventional monetary policy become less effective in high EPU contexts. In this sense, unconventional monetary-policy policies such as forward guidance can be useful tools in anchoring economic agents' expectations, thereby reducing EPU and helping the economy to recover after a crisis.

Third, the asymmetric effects of both conventional and unconventional monetary policy when EPU is high should lead monetary authorities to factor in the firm-level impact of monetary policy to enhance its effectiveness in times of economic distress. For instance,

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central banks could limit their corporate bond purchasing programs to those sectors and subsectors that are more likely to be affected by expansionary monetary-policy shocks. Fourth, given the negative influence of expansionary monetary policy on innovation, governments could provide tax incentives on R&D investments in times of economic distress to encourage firms to undertake new R&D projects. Lastly, the negative effect of a decrease in EPU on R&D investment could be offset via R&D subsidies aimed at incentivizing such investments when the economy is growing.

Future research could go in two directions. First, a potential line of research could examine the existence of asymmetries based on other firm-level characteristics with the aim of improving our understanding of the investment-based transmission mechanisms of both conventional and unconventional monetary policy. Similarly, there might be firm-level asymmetries in the effects of EPU and monetary policy on R&D investment analyzed in Chapter 4. Future research could try to detect and explore if such asymmetries exist and to what extent they affect R&D investment in different sectors and types of firms. Another line of research could draw upon our analysis in Chapter 4 but replacing R&D projects for investments in non-R&D growth options. This may provide a further attractive test for our hypotheses and their policy implications.

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## Appendix A – Tables and Figures

**Table A – Panel VAR Estimations: Figures 1 and 2**

	<b>Figure 1</b>	<b>Figure 2</b>	<b>Figure 2</b>
	Whole sample	Low uncertainty	High uncertainty
$I_{i,t-1}$	.2291*** (.0247)	.2266*** (.0284)	.2511*** (.0423)
$Q_{i,t-1}$	.8407*** (.0456)	.6543*** (.0438)	1.021*** (.0895)
$CF_{i,t-1}$	.015 (.0168)	.0009 (.0203)	.0554** (.0282)
$MPR_{t-1}$	-.0255*** (.006)	-.0188*** (.0061)	.0107 (.0169)

Investment ( $I_i$ ), measured as capital expenditures in the year of observation divided by gross fixed assets at the beginning of the year, is the dependent variable. \*\* and \*\*\* indicate statistical significance at 5 and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 4$  are used as instruments for the variables of the models in differences.

**Table B – Lag selection: Figures 1 and 2**

	<b>Figure 1</b>	<b>Figure 2</b>	<b>Figure 2</b>
	All the sample	Low uncertainty	High uncertainty
Lags	Adjusted CD	Adjusted CD	Adjusted CD
1	.9882	.9873	.9996
2	.9949	.9913	.9951

Adjusted coefficients of determination for models with 1 and 2 lags. Results are inconclusive since models corresponding to Figure 1 and Figure 2 (low uncertainty) point to two lags, whereas the model corresponding to Figure 2 (high uncertainty) suggests one lag. Nonetheless, differences are negligible. For the sake of comparison between models and for parsimony, we choose the same lag-length for all three models: one lag.

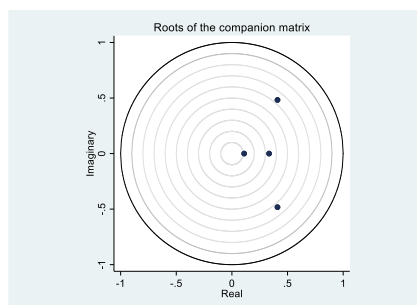
**Figure A – Stability tests: Figures 1 and 2**

Figure 1

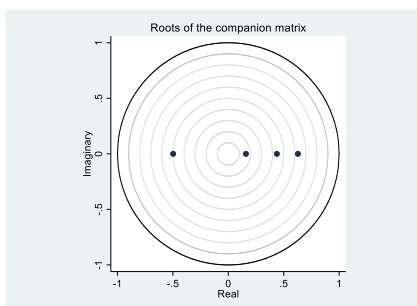


Figure 2 (low)

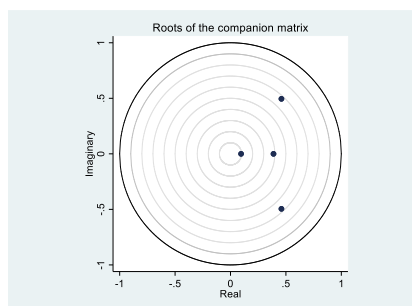


Figure 2 (high)

**Fig. A.** Stability tests corresponding to Table A. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

**Table C – Dynamic Panel Threshold Model**

	Lower regime	Upper regime
$I_{i,t-1}$	-.2578*** (.0038)	.0226*** (.0077)
$Q_{i,t-1}$	.3480*** (.0085)	-.0043 (.0145)
$CF_{i,t-1}$	.0858*** (.0048)	.0504*** (.0093)
$MPR_{t-1}$	.0379*** (.0023)	-.1108*** (.0105)
<i>Threshold (EPU index)</i>		<b>149.271***</b> <b>(1.2639)</b>
<i>Linearity (p – value)</i>		0.00

Investment ( $I_i$ ), measured as capital expenditures in the year of observation divided by gross fixed assets at the beginning of the year, is the dependent variable. \*\*\* indicates statistical significance at 5 and 1% levels. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 4$  are used as instruments for the variables of the models in differences. The estimated threshold coincides almost exactly with the 75<sup>th</sup> percentile of the EPU index.

Table D – Panel VAR estimations: Figures 4 to 6

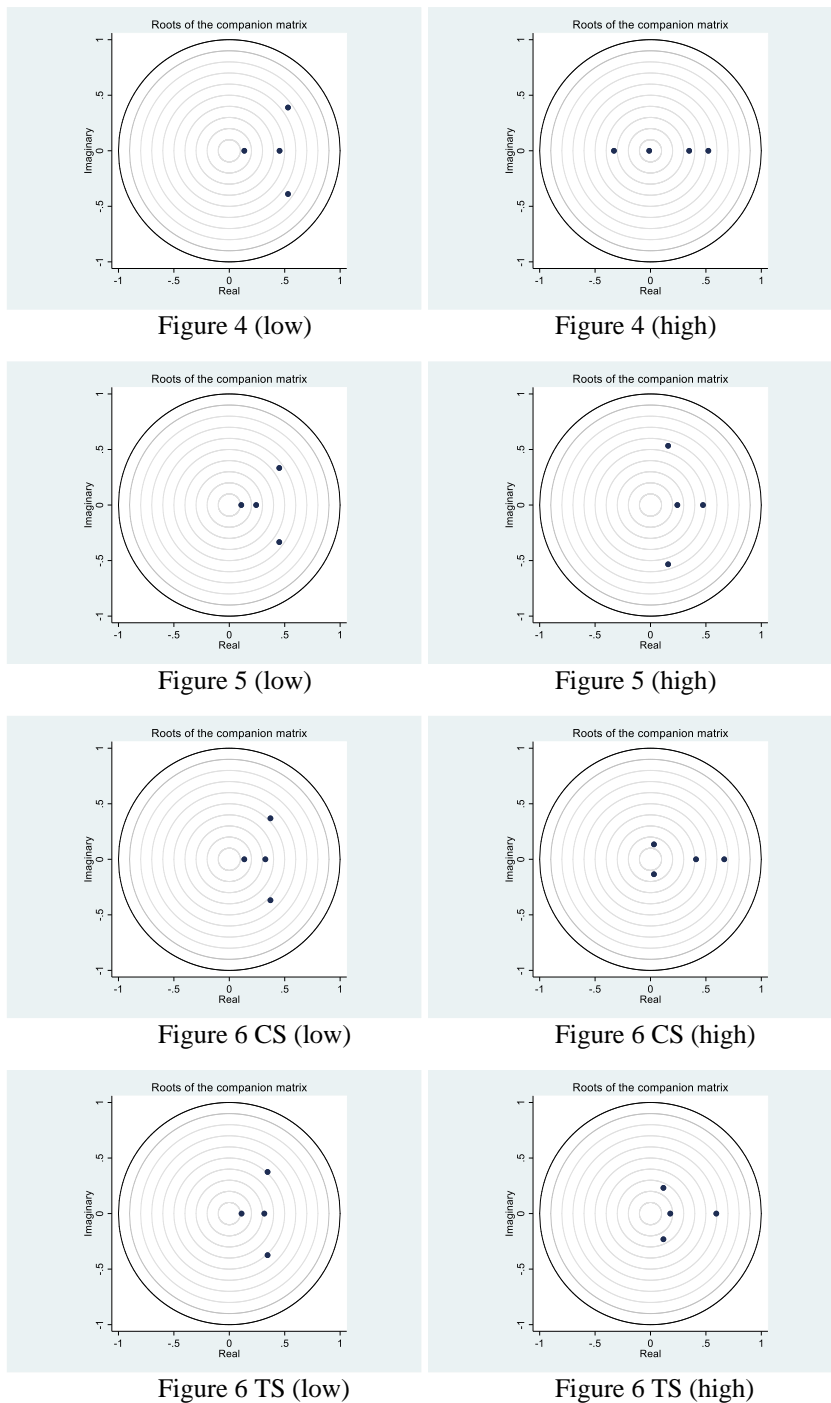
	Figure 4: Shadow rate			Figure 5: VIX index			Figure 6: Corporate spread			Figure 6: TED spread		
	Low	High		Low	High		Low	High		Low	High	
	uncertainty	uncertainty		uncertainty	uncertainty		uncertainty	uncertainty		uncertainty	uncertainty	
$I_{t,t-1}$	.2659*** (.0305)	.1811*** (.0406)		.2529*** (.0284)	.2259*** (.0547)		.2517*** (.0268)	.295*** (.0485)		.2591*** (.0271)	.2089*** (.0498)	
$Q_{t,t-1}$	.6118*** (.0518)	.8873*** (.0955)		.7337*** (.0579)	.8438*** (.0805)		.747*** (.0521)	.4492*** (.1274)		.6805*** (0.545)	.07114*** (.0674)	
$CF_{t,t-1}$	.0069 (.0238)	.1415*** (.0263)		.0361** (.0171)	.0288 (.0583)		-.034* (.0174)	.0439 (.0348)		.0154 (.0176)	.0751* (.0422)	
$MPR_{t-1}$	-.0255*** (.0064)	-.0293 (.0123)		-.0281*** (.00641)	-.0151 (.0116)		-.0308*** (.006)	.0471** (.0187)		.0345*** (.0079)	-.0004 (.0077)	

Investment ( $I_t$ ), measured as capital expenditures in the year of observation divided by gross fixed assets at the beginning of the year, is the dependent variable. \*, \*\*, and \*\*\* indicate statistical significance at 10, 5, and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 4$  are used as instruments for the variables of the models in differences.

Table E – Lag selection: Figures 4 to 6

Lags	Figure 4: Shadow rate			Figure 5: VIX index			Figure 6: Corporate spread			Figure 6: TED spread		
	Low	High		Low	High		Low	High		Low	High	
	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	Adjusted CD	
1	.99367	.9992	.9953	.9953	.9995	.9995	.9938	.9999	.9971	.9971	.9968	
2	.9954	.9896	.9963	.9963	.9807	.9949	.9949	.9361	.9945	.9945	.9972	

Adjusted coefficients of determination for models with 1 and 2 lags. Results are inconclusive. For the sake of comparison between models and for parsimony, we choose the same lag-length for all models: one lag.

**Figure B – Stability tests: Figures 4 to 6**

**Fig. B.** Stability tests corresponding to Table D. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

Table F – Panel VAR estimations: Figures 7 to 9

	Figure 7: Investment irreversibility $PPE_{i,t}$		Figure 8: Operational inflexibility $OF_{i,t}$		Figure 9: Market power $PCM_{i,t}$	
	Low irreversibility	High irreversibility	Low inflexibility	High inflexibility	Low market power	High market power
$I_{i,t-1}$	.0863 (.0613)	.3674*** (.0547)	.2664*** (.0541)	.1843*** (-.0626)	.408*** (.0604)	.1934*** (.0575)
$Q_{i,t-1}$	.07534*** (.1292)	1.2031*** (.1118)	1.2366*** (0.1176)	.7719*** (.1371)	1.1318*** (.1489)	.7845*** (.1038)
$CF_{i,t-1}$	-.0119 (.0394)	-.03 (.038)	.051 (.0367)	-.0211 (.0457)	.0728* (.0402)	.0949** (.0387)
$MPR_{t-1}$	-.0057 (.0242)	-.0571** (.0225)	.0415* (.0247)	-.0099 (.0236)	.0296 (.0259)	-.0194 (.0228)

Investment ( $I_{i,t}$ ), measured as capital expenditures in the year of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. We divide the sample for  $PPE_{i,t}$  and  $OF_{i,t}$  using a dummy that takes the value 1 if the observation is above the median of the sample (high), and 0 otherwise (low). For  $PCM_{i,t}$ , the dummy takes the value 1 when the variable is above the industry median. \*, \*\*, and \*\*\* indicate statistical significance at 10, 5, and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 4$ .

Table G – Lag selection: Figures 7 to 9

Lags	Figure 7: Investment irreversibility $PPE_{i,t}$		Figure 8: Operational inflexibility $OF_{i,t}$		Figure 9: Market power $PCM_{i,t}$	
	Low irreversibility	High irreversibility	Low inflexibility	High inflexibility	Low market power	High market power
1	.9998	.9999	.9998	.9997	.9998	.9998
2	.998	.9970	.9972	.9975	.9963	.9977

Adjusted coefficients of determination for models with 1 and 2 lags. Results suggest that the optimal lag length for all models is one.

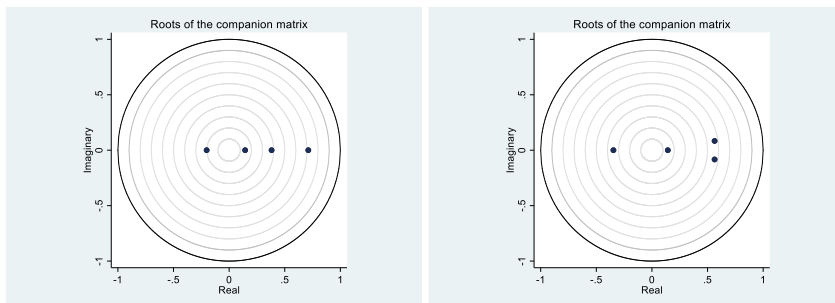
**Figure C – Stability tests: Figures 7 to 9**

Figure 7 (low)

Figure 7 (high)

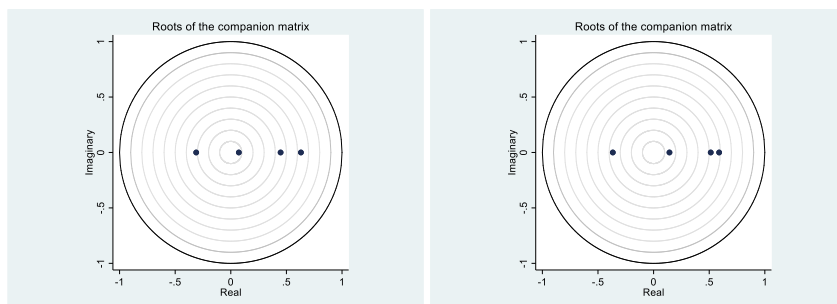


Figure 8 (low)

Figure 8 (high)

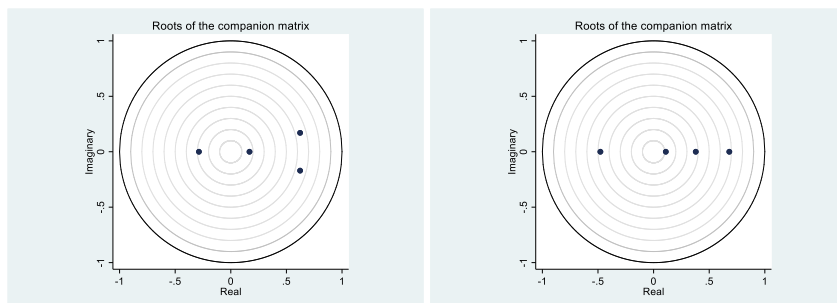


Figure 9 (low)

Figure 9 (high)

**Fig. C.** Stability tests corresponding to Table F. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

Table H - Panel VAR estimations: Figure 12

	Figure 12a	Figure 12b	Figure 12c	Figure 12d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	.0618 (.0386)	-.0275 (.041)	.1369*** (.0221)	-.2692*** (.0445)
$Q_{i,t-1}$	1.229*** (.0855)	1.277*** (.1131)	.601*** (.1451)	1.675*** (.1575)
$CF_{i,t-1}$	-.1733*** (.0168)	-.2143*** (.151)	-.1378*** (.0164)	-.4299*** (.0233)
$(UMP_t * dummyQE)_{t-1}$	-.0528*** (.0109)	-.0278*** (.0065)	-.141*** (.0188)	-.0006 (.0007)
Hansen's J statistic	138.9	147.5	147.7	150.92
$p$ - value	.603	.403	.4	.33
Degrees of freedom	144	144	144	144

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*\*\* indicates statistical significance at a 1% level. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 11$  are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982).

Table I - Lag selection: Figure 12

Lags	Figure 12a	Figure 12b	Figure 12c	Figure 12d
	BIC	BIC	BIC	BIC
1	-615.86	-607.3	-607.14	-603.89
2	-547.08	-547.34	-537.43	-546.61
3	-478.51	-470.98	-465.85	-486.28
4	-414.19	-415.68	-396.78	-422.37

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.



Table J - Panel VAR estimations: Figure 13

	Figure 13a	Figure 13b	Figure 13c	Figure 13d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	.2615** (.1258)	.2654** (.1187)	.0176 (.0337)	-.0346 (.0383)
$Q_{i,t-1}$	-.4822 (.4078)	-.4483 (.3936)	.651*** (.2039)	.2267 (.1858)
$CF_{i,t-1}$	.0048 (.0741)	-.0218 (.0791)	-.0997*** (.0202)	.1758*** (.0345)
$(UMP_t * dummyFG)_{t-1}$	-.0988** (.0502)	-.0603** (.0275)	-.0725*** (.0187)	.00144*** (.0005)
Hansen's J statistic	107	103.2	151.88	144.2
$p - value$	.616	.712	.311	.479
Degrees of freedom	112	112	144	144

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*\* and \*\*\* indicate statistical significance at 5 and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 4$  to  $t - 11$  (Figures 13a and 13b) and from  $t - 2$  to  $t - 11$  (Figures 13c and 13d) are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982).

Table K - Lag selection: Figure 13

Lags	Figure 13a	Figure 13b	Figure 13c	Figure 13d
	BIC	BIC	BIC	BIC
1	-482.27	-485.22	-602.99	
2	-418.54	-421.23	-554.39	
3	-363.66	-366.4	-478.36	
4	-283.25	-286.39	-425.24	

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

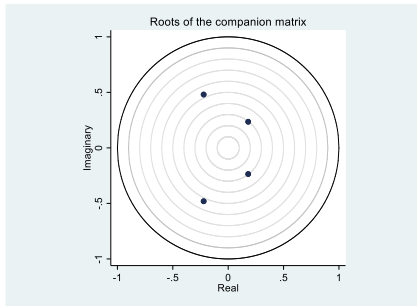
**Figure D – Stability tests: Figures 12 and 13**

Figure 12a

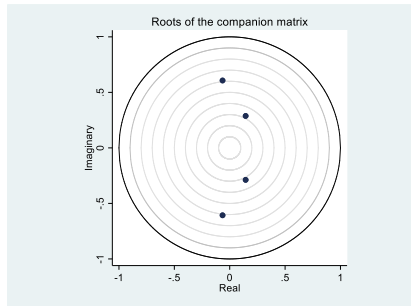


Figure 12b

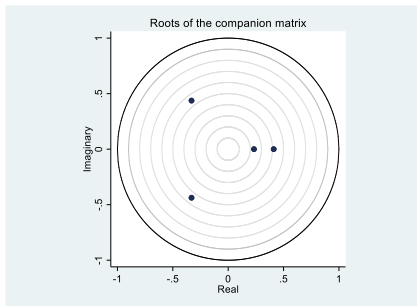


Figure 12c

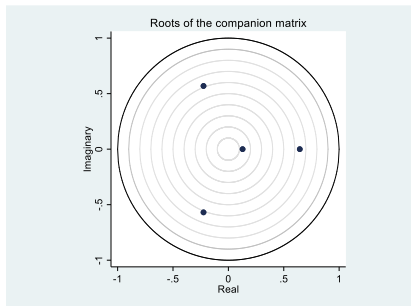


Figure 12d

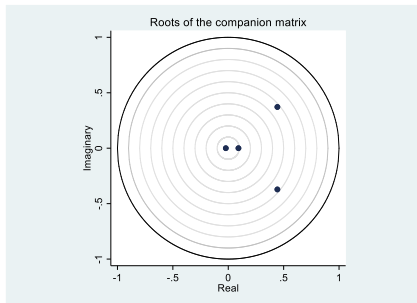


Figure 13a

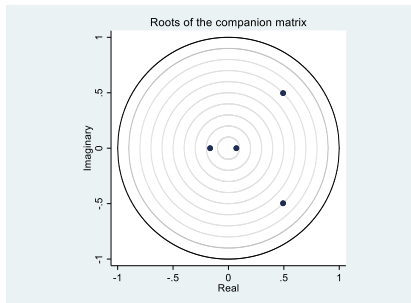


Figure 13b

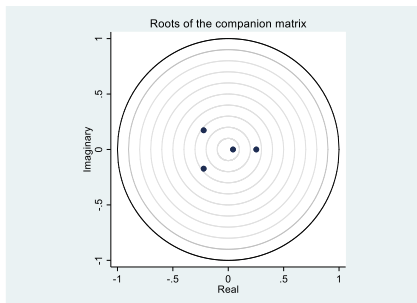


Figure 13c

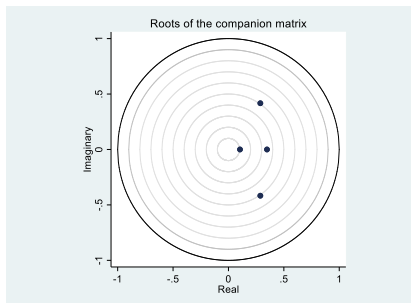


Figure 13d

**Fig. D.** Stability tests corresponding to Tables H and J. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

Table L - Panel VAR estimations: Figure 14

	Figure 14a	Figure 14b	Figure 14c	Figure 14d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	.0663*** (.0222)	-.0812*** (.0267)	.1888*** (.0191)	-.2903*** (.0201)
$Q_{i,t-1}$	.8297*** (.0955)	.9788*** (.0893)	-.0788 (.1161)	1.578*** (.0865)
$CF_{i,t-1}$	-.1835*** (.0140)	-.2324 (.0129)	-.1814*** (.0149)	-.2964*** (.0141)
$(UMP_t * dummyQE)_{t-1}$	-.0624*** (.0061)	-.0284*** (.0035)	-.1886*** (.0132)	-.0007** (.0003)
Hansen's J statistic	151.92	153.48	160.03	160.41
p - value	.575	.711	.573	.565
Degrees of freedom	164	164	164	164

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*\* and \*\*\* indicate statistical significance at 5, and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t-2$  to  $t-11$  are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982). Industry spillovers are controlled for.

Table M - Lag selection: Figure 14

Lags	Figure 14a	Figure 14b	Figure 14c	Figure 14d
	BIC	BIC	BIC	BIC
1	-699.73	-706.17	-699.61	-699.24
2	-599.67	-592.5	-591.95	-608.94
3	-490.82	-485.69	-477.18	-485.42
4	-387.17	-388.43	-375.49	-390.06

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

Table N - Panel VAR estimations: Figure 15

	Figure 15a	Figure 15b	Figure 15c	Figure 15d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	.1573*** (.0364)	.2044*** (.0408)	.0708** (.0307)	.0554* (.0301)
$Q_{i,t-1}$	-.1519 (.1446)	-.1349 (.1729)	.2502* (.13)	.2851 (.189)
$CF_{i,t-1}$	.1911*** (.0274)	.1041*** (.025)	-.1258*** (.014)	.2375*** (.0282)
$(UMP_t * dummyQE)_{t-1}$	-.071*** (.0095)	-.0477*** (.005)	-.0611*** (.0204)	.0036*** (.0004)
Hansen's J statistic	173.85	164.15	159.05	165.45
$p - value$	.51	.711	.595	.454
Degrees of freedom	175	175	164	164

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*, \*\*, and \*\*\* indicate statistical significance at 10, 5, and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 4$  to  $t - 11$  (Figures 15a and 15b) and from  $t - 2$  to  $t - 11$  (Figures 15c and 15d) are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982). Industry spillovers are controlled for.

Table O - Lag selection: Figure 15

Lags	Figure 15a	Figure 15b	Figure 15c	Figure 15d
	BIC	BIC	BIC	BIC
1	-700.56	-702.36	-700.6	-694.19
2	-594.03	-595.79	-602.55	-610.79
3	-504.66	-513.8	-490.7	-508.16
4	-399.59	-398.47	-389.05	-399.7

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

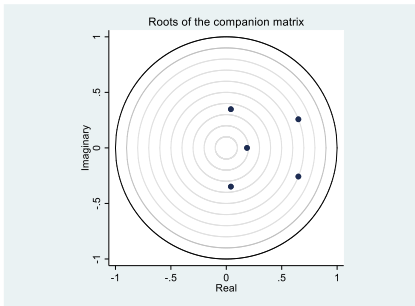
**Figure E – Stability tests: Figures 14 and 15**

Figure 14a

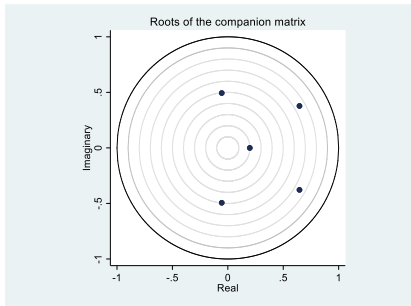


Figure 14b

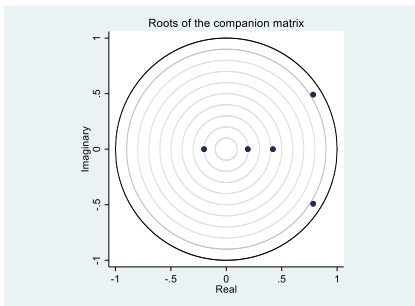


Figure 14c

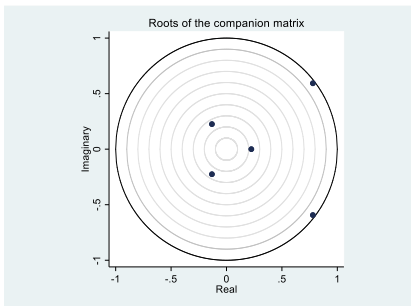


Figure 14d

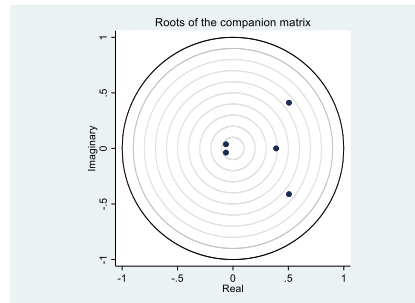


Figure 15a

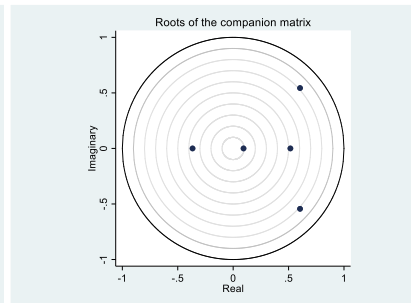


Figure 15b

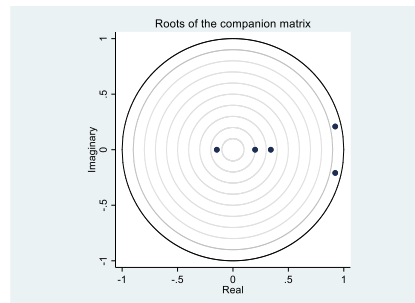


Figure 15c

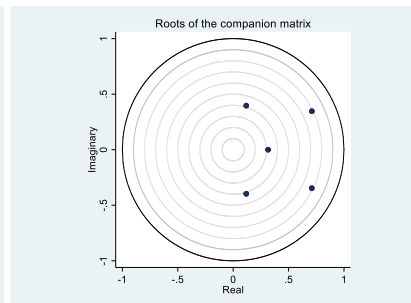


Figure 15d

**Fig. E.** Stability tests corresponding to Tables L and N. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

Table P - Panel VAR estimations: Figure 16

	Figure 16a	Figure 16b	Figure 16c	Figure 16d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	.0538*** (.0172)	-.0335 (.0219)	-.1982*** (.0302)	-.0891 (.0273)
$Q_{i,t-1}$	1.368*** (.0956)	1.524*** (.1157)	-.651*** (.0963)	1.675*** (.1012)
$CF_{i,t-1}$	-.1506*** (.0122)	-.1884*** (.0161)	.1244*** (.0266)	-.3384*** (.0142)
$(UMP_t * dummyQE)_{t-1}$	-.0839*** (.0063)	-.0308*** (.0044)	-.1751*** (.0235)	.0005 (.0004)
Hansen's J statistic	164.44	168.92	174.73	167.88
$p - value$	.476	.38	.492	.401
Degrees of freedom	164	164	175	164

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*\*\* indicates statistical significance at a 1% level. Standard errors are in parentheses. All variables in levels lagged from  $t - 2$  to  $t - 11$  (Figures 16a, 16b, and 16d) and from  $t - 4$  to  $t - 11$  (Figures 16c) are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982). The term spread is controlled for.

Table Q - Lag selection: Figure 16

Lags	Figure 16a	Figure 16b	Figure 16c	Figure 16d
	BIC	BIC	BIC	BIC
1	-695.21	-690.72	-693.35	-691.76
2	-575.89	-590.85	-576.65	-598.44
3	-575.9	-488.4	-495.77	-500.71

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

Table R - Panel VAR estimations: Figure 17

	Figure 17a	Figure 17b	Figure 17c	Figure 17d
	10-year U.S. government bond yield	Moody's seasoned Aaa corporate bond yield	Shadow rate	Wilshire 500 Total Market Index
$I_{i,t-1}$	-.1291*** (.0463)	.1212** (.0552)	.0842*** (.0237)	-.0384 (.035)
$Q_{i,t-1}$	.4607*** (.1529)	1.26*** (.2622)	.7069 (.1656)	1.091*** (.1611)
$CF_{i,t-1}$	-.0777** (.0361)	.0572 (.0358)	-.1005*** (.0144)	-.4145*** (.021)
$(UMP_t * dummyQE)_{t-1}$	-.1464*** (.0153)	.0106 (.0089)	-.12.28*** (.027)	-.003*** (.0004)
Hansen's J statistic	174.46	181.43	167.52	160.28
p - value	.497	.354	.409	.567
Degrees of freedom	175	175	164	164

Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. \*\* and \*\*\* indicate statistical significance at 5 and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 4$  to  $t - 11$  (Figure 17a),  $t - 2$  to  $t - 9$  (Figure 17b), and from  $t - 2$  to  $t - 11$  (Figure 17d) are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982). The term spread is controlled for.

Table S - Lag selection: Figure 17

Lags	Figure 17a	Figure 17b	Figure 17c	Figure 17d
	BIC	BIC	BIC	BIC
1	-687.29	-798.94	-692.13	-699.36
2	-598.45	-703.34	-582.41	-621.66
3	-507.39	-590.87	-494.25	-512.85

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

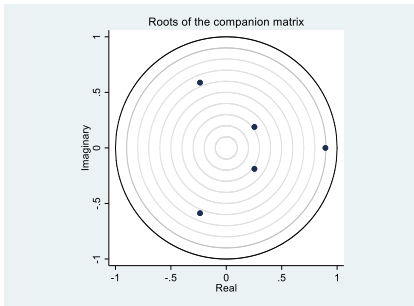
**Figure F – Stability tests: Figures 16 and 17**

Figure 16a

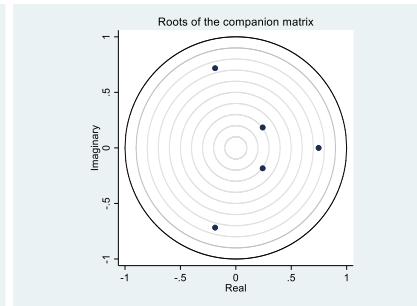


Figure 16b

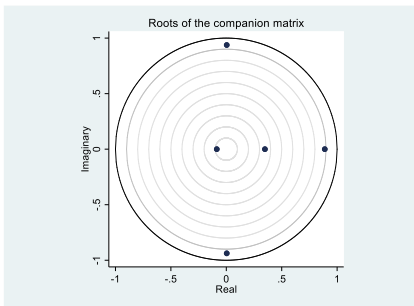


Figure 16c

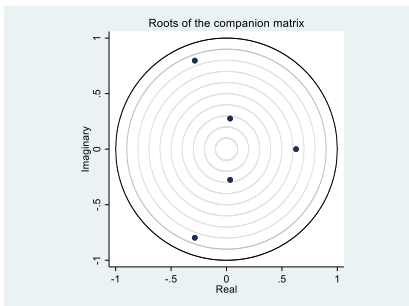


Figure 16d

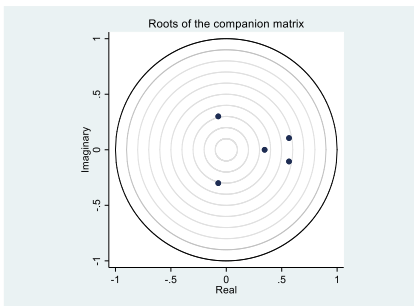


Figure 17a

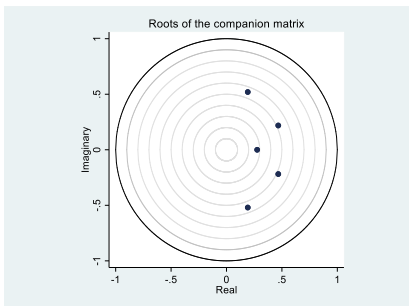


Figure 17b

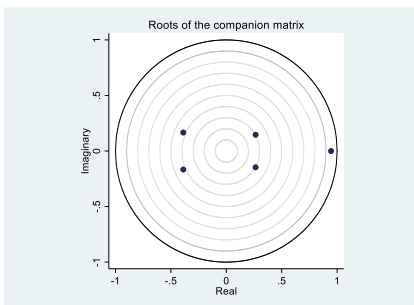


Figure 17c

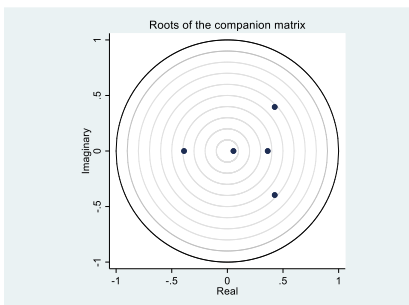


Figure 17d

**Fig. F.** Stability tests corresponding to Tables P and R. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.



Table T - Panel VAR estimations: Figures 18 to 20

	Figure 18		Figure 19		Figure 20	
	Investment irreversibility		Operational inflexibility		Market power	
	Low	High	Low	High	Low	High
$I_{t,t-1}$	.0927 (.1874)	-2.2185 (.2452)	.3099*** (.1131)	.1619* (.0971)	.5015*** (.057)	.4565*** (.1182)
$Q_{t,t-1}$	2.111*** (.5837)	-1.091 (1.227)	-1.472*** (.5242)	-2.095 (.4774)	.2764 (.4188)	-1.2384** (.6052)
$CF_{t,t-1}$	.3396 (.2199)	.1315 (.2072)	.1321** (.0572)	-.6301*** (.0557)	-.1119*** (.0202)	-.3764*** (.1118)
$(AAA_t * dummyQEFQ)_{t-1}$	-.12.51** (.0613)	-.0074 (.0446)	-.0307** (.0177)	-.0215** (.0117)	-.0444*** (.0067)	.0061 (.0175)
Hansen's J statistic	58.48	57.14	91.2	106.2	91.55	112.58
$p - value$	.671	.716	.618	.223	.61	.119
Degrees of freedom	64	64	96	96	96	96

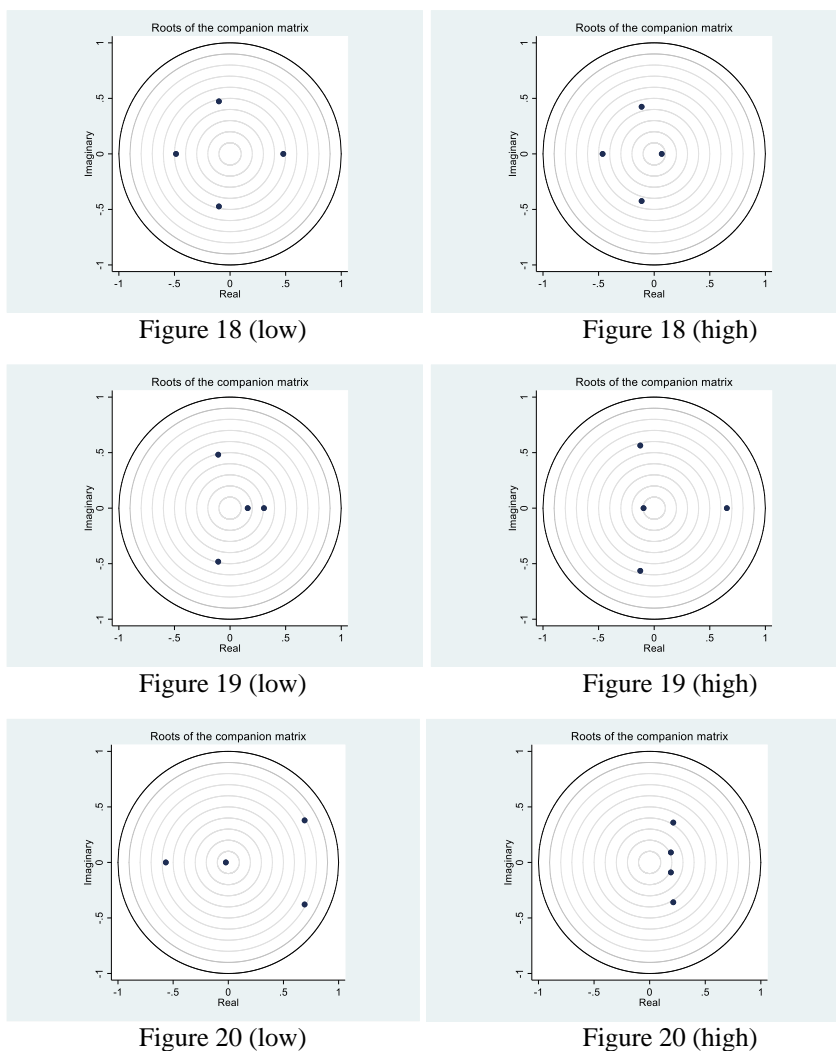
Investment ( $I_t$ ), measured as capital expenditures in the quarter of observation divided by gross fixed assets at the beginning of the quarter, is the dependent variable. We divide the sample for investment irreversibility, operational inflexibility, and market power using a dummy that takes the value 1 if the observation is above the industry median in each quarter (high), and 0 otherwise (low). \*, \*\*, and \*\*\* indicate statistical significance at 10, 5, and 1% levels, respectively. Standard errors are in parentheses. All variables in levels lagged from  $t - 4$  to  $t - 8$  (Figure 18) and from  $t - 2$  to  $t - 8$  (Figures 19 and 20) are used as instruments for the variables of the models in differences. Hansen's J statistic tests the null hypothesis of the joint validity of instruments (Hansen 1982).

Table U - Lag selection: Figures 18 to 20

Lags	Figure 18		Figure 19		Figure 20	
	Low	High	Low	High	Low	High
	BIC	BIC	BIC	BIC	BIC	BIC
1	-235.7	-291.30	-404.58	-369.51	-365.62	-400.75
2	-170.9	-229.40	-343.60	-320.96	-307.07	-350.88
3	-134.35	-161.51	-275.60	-264.71	-240.42	-280.60
4	-68.9	-84.49	-216.35	-194.54	-196.62	-214.57

Lag-length selection is based on the Bayesian Information Criterion (BIC) for GMM models proposed by Andrews and Lu (2001). Results point to one lag in all models.

## Figure G – Stability tests: Figures 18 to 20



**Fig. G.** Stability tests corresponding to Table T. All the eigenvalues lie inside the unit circle. Therefore, all models satisfy the stability condition.

**Table V– Hausmann Test**

Dependent variable:	$RD1_{i,t}$	$RD2_{i,t}$	$RD3_{i,t}$
$\chi^2$	1425.5***	1298.88***	1118.01***

Hausman test for models using  $RD1_{i,t}$ ,  $RD2_{i,t}$ , and  $RD3_{i,t}$  as dependent variables. \*\*\* indicates statistical significance at a 1% level. The null hypothesis is rejected. Consequently, we choose fixed effects over random effects.